CESMII
THE SMART MANUFACTURING INSTITUTE

The 15th Anniversary of Smart Manufacturing

Grassroots Leadership, Greater Good, Timing, and Perseverance

By Jim Davis, UCLA - Perspective of a Co-founder

PREFACE

Today, Smart Manufacturing (SM) is a national capability that has been written into U.S. legislation. It is a term used in national planning, and it appears ubiquitously, often together with Industry 4.0. There was a time that Smart Manufacturing and Industry 4.0 did not exist nor did the Smart Manufacturing Leadership Coalition (SMLC) or the Clean Energy Smart Manufacturing Innovation Institute (CESMII). There was also a time when we would 'Google' smart manufacturing and get only a few hits. I repeated our "scientific measure" of SM progress[1] for 2022 and observed a substantially larger number of Google hits at 1,040,000,000.

Since I am the one person who can connect the dots from the very beginning, I felt that 15 years is a good point in time to write an accounting of SM's origins since my memory is probably peaking. With SM so deeply a part of my life and professional career for so many years, taking the time to remember, document, laugh, and celebrate (just a little) about how it all came to be became a most enjoyable writing exercise. There are the documents that jogged key memories, as well as many undocumented sidenotes that had stuck in my memory.

Most importantly, writing this has allowed me to reconnect with so many people who became colleagues and friends throughout the years. It is impossible to name everyone involved in the early days, but there was a group of people who were instrumental with leadership, breaking through barriers, and/or carrying on the cause of SM today. This memoir recognizes these people according to my memory (my disclaimer). The larger point, though, is that it is nothing short of amazing how many people came together to make SM happen and even more striking how the collective capacity and persistence of an early grassroots community that produced concepts that have remained largely true 15 years later – concepts for manufacturing that have so much potential for the greater good of our planet.

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[1]Started by Dean Bartles, Manufacturing Technology Development Group, on the Smart Manufacturing Leadership Coalition

There is an important human orientation to SM that threads through every aspect and I was thankful to have had personal indoctrination from many about all the ways people are central to SM amid all of the technology. My CIO responsibilities at UCLA for campus privacy and digital access for people with disabilities have been an important influence. Privacy, and equity, diversity, and inclusion continue to grow into critical importance today. I owe much to several UCLA faculty, the UCLA Chief Privacy Officer, and UCLA's Legal Counsel for instructing me on the distinctions between privacy and security, to the Disabilities Computing Program for teaching me how technology can enhance inclusion, and to those on my UCLA Office of Advanced Research Computing (OARC) Management Team and Staff who supported this initiative by always recognizing that our partnerships, communications, and administrative tasks are about how we present ourselves to others[2]. There is also an indescribable debt of gratitude to my wife and daughters who patiently listened about SM for many years, while convinced that science and engineering were not for them. Their interests in social work, political science, and media not only kept a semblance of balance on the home front but also continually underscored the point that SM brings value as a human-centered endeavor enabled by technology, not the other way around.

The human dimension of SM has been there from the beginning, advocated for by many, despite all the technologies. This theme has also come full circle with the resurgence of AI (Artificial Intelligence) and ML (Machine Learning), which has reminded us of the principle that an algorithm needs to be interpreted, understood, and trusted by people. I have personally leaned on our early work in AI in the '80s that emphasized causal explainability of the data, modeling, and mathematics for building toward trustworthy AI today.

The origins of Smart Manufacturing as a national initiative are no doubt a subjective matter, however, reasonable bookends focus us on a seven-year period. One bookend comes from recognizing that the first use of the term "Smart Manufacturing" was in 2007, but traceable back to a National Science Foundation (NSF) workshop that occurred in September 2006 with concept discussions that extend back into 2005. The other bookend stems from one of the most remarkable days in November 2014 when the Department of Energy (DOE) issued a Notice of Intent (NOI) to expect a Funding Opportunity Announcement (FOA) about a national Smart Manufacturing Institute. The national phase of Smart Manufacturing can be reasonably argued to have occurred at this point.

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[2] Kent Wada, UCLA/OARC Chief Privacy Officer; Amy Blum, UCLA Legal Counsel; Christine Borgman, UCLA Distinguished Professor in Information Science; Kelly Arruda, UCLA/ITS IT Campus Governance; Davida Johnson, UCLA/OARC Managing Director; Rose Rocchio, UCLA/OARC Director, incl. Disabilities Computing Program; Lisa Snyder, UCLA/OARC Director; Barbara Woltag, UCLA/OARC Administrative Analyst; Aaron Taber, UCLA/Research Complance Deputy Export Control Officer.

The concept of CESMII did not yet exist, but this was the point in time that the Smart Manufacturing Leadership Coalition (SMLC) switched to the question of whether or not to lead a proposal. There is a sequel to this write-up that could be undertaken to describe the process and decisions that ensued after that NOI that ultimately resulted in the formation of CESMII.

However, jumping forward seven years from the NOI, CESMII is now in its fifth year with many of the elements conceived in 2006 now coming to fruition and having an impact. Put another way, CESMII is literally the continuation of a decade-long development of SM by one of the earliest industry-academic-government public-private partnerships. CESMII today is positioned to continue to drive, expand, and accelerate economic, energy, environmental, and social impacts by breaking down the barriers to wide industry adoption.

The Origins of Smart Manufacturing

THE STAGE WAS SET BY 2005

By 2005, Tom Edgar, Professor of Chemical Engineering at University of Texas, Austin, had already spent decades researching, developing, and expanding process control with a wide array of data and intelligent systems modeling and applications. His work, which was seminal to industrial application and the education of process control, was motivated by significant industry involvement through the Texas-Wisconsin-California Control Consortium (TWCCC), an industry-university research consortium he had co-founded. Jim Porter, Chief Engineer and Vice President of Engineering and Operations at DuPont, had co-founded an industry consortium, Foundations of Integrated and Automated Technologies (FIATECH), focused on accelerating the development, demonstration, and deployment of fully 'integrated and automated technologies' to deliver the highest business value throughout the lifecycle of all types of capital projects. FIATECH developed a roadmap to ensure that the right automation technologies are developed to deliver the highest value across all project phases and process operations. My graduate students and I had been collaborating with a tight group of researchers, students, and colleagues around the country[3] doing some of the first work on AI and intelligent systems in process design, operational diagnostics, and abnormal event prevention in the '80s and '90s at "The" Ohio State University. Tom and I were both long-time trustees of an academic-industry organization called Computer Aids for Chemical Engineering (CACHE), which was devoted to the development and distribution of computer related and/or technology-based educational aids for the chemical engineering profession.

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[3]George Stephanopoulos, MIT; Mark Kramer, currently with MITRE; Venkat Venkatasubramanian, Columbia/Purdue; Lyle Ungar, University of Pennsylvania; David Himmelblau, University of Texas, Austin; and Balakrishnan Chandrasekaran, John Josephson, Don Miller, and Brian Hajek at Ohio State University.

In the late ’90s and early 2000s, I had become a university ‘CIO’ at the Ohio State University (just before CIOs became a title) and then the first CIO at UCLA in 2000 putting me squarely into that period in which computation was rapidly increasing in capacity, the Internet was scaling globally, and Enterprise Resource Planning (ERP) systems had become a business priority. Tom had also become involved in university CIO activities as the Associate Vice President for Academic Computing and Instructional Technology Services at UT Austin. IT and digital manufacturing technologies were two very, very different worlds. For me, a decade of industry AI projects became intertwined with my recent involvement in the Honeywell Abnormal Situation Management (ASM) Consortium and my CIO role in which I was implementing production networked applications and ERP systems at scale. The ASM consortium was led by Honeywell and had formed through a National Institute of Standards and Technology (NIST) Advanced Technology Program (ATP) grant in 1994 to address alarm management, operator display design, and human-machine operational practice for managing abnormal situations. It is remarkable to go back and read the original NIST ATP proposal because it contained early concepts for shared plug-and-play AI system tools that are in the discussion today.

THE SPARK THAT STARTED SM

These industry and academic consortia had each formed and were largely operating independently well before 2005, but each had embraced the Internet, which was just becoming a scaled capability. Each also had a common objective of using data, modeling, and automation to expand the scope of control, operational management, and decision-making across factories, enterprises, and supply chains for increased business value, zero emissions, and zero incident operations. When taken together these four consortia represented a huge base of digital and enterprise thinking about operational systems combined with industry application, educational need, and manufacturing foresight. The spark that brought Tom Edgar, Jim Porter, and me and these four consortia together was generated by the vision and leadership of Maria Burka and Bruce Hamilton, Program Directors for the Chemical, Bioengineering, Environmental and Transport Systems Division at NSF. In 2005, Cyberinfrastructure (CI) had become a computer science reality, raising questions about what was possible with this higher-level implementation capability of the Internet. Maria and Bruce had reached out about a workshop to consider the role of CI in next-generation areas of strength for the U.S in Chemical and Biological Systems.

We learned years later that NSF did not see much value in considering CI and manufacturing at this time, but Maria and Bruce persevered, and the workshop became a reality. We also learned later that the workshop, which was to have been held at NSF facilities (reserved for the priority meetings), had been bumped for something considered a higher priority. Nevertheless, the workshop was eventually organized with significant industrial involvement and took place at a nearby hotel in Arlington in September 2006, bringing industry, academic, and government leaders and experts to consider how CI might apply to process systems and operations.

Even then CI was recognized for its capacity to scale and flatten. Perhaps the fact that Thomas Friedman's book, "The World is Flat: A Brief History of the Twenty-First Century," had just been published was a timely influence. What emerged from that 2006 workshop was a remarkably voiced, industry, academic, and government recommendation about re-envisioning next-generation process manufacturing as a national priority. The significantly new and expansive operational and economic impact was seen as possible using intelligent systems, automation, the Internet, and CI in highly scaled ways. We chose to settle on a definition of CI going into the workshop. In retrospect, driving the workshop from the definition below had to have been either instrumental in shaping SM or it contained the tag lines that resonated with what people were already thinking:

"Cyberinfrastructure is the coordinated aggregation of software, hardware, and other technologies, as well as human expertise, to (1) support current and future discoveries in science and engineering and (2) integrate relevant and often disparate resources to provide a useful, usable, and enabling computational and data framework characterized by broad access."

Regardless, it was a remarkable re-envisioning of manufacturing to come from a single workshop. Notably, the workshop was designed around invited participant teams who were asked to summarize the outcomes of the workshop. One of these invited teams brought industry leaders Don Clark (Invensys), Jerry Gipson (Dow), Kevin Harris (Honeywell ASM), and Jim Porter (DuPont) together, who jointly described an area called, "Zero Incident Zero Emissions Smart Plant Operations." This one-page write-up introduced the term "Smart Plants," brought FIATECH and ASM objectives together, and opened a new kind of discussion between practitioners and providers. From my vantage point as workshop chair, we were able to construct a set of principles that formed the origins of Smart Manufacturing (before it was named). The conclusions below from the 2006 workshop report remain remarkably true 15 years later:

- *The focus on 'knowledge' and 'information' as U.S. economic drivers points to the demand for the development of CI applications on an industry-wide scale and a need to prepare and train for significant operational change within the industry*

- *It is in the best interests of this community [industry-academic-government] to:*
    - *Focus on stakeholder/sponsor engagement, large-scale concepts, opportunities for industry, and exploiting the general industry-academia research alignment.*
    - *Influence and/or build the cyberinfrastructure to meet the needs, mobilize collective resources, and take advantage of the national cyberinfrastructure to begin addressing larger scope problems.*

- *Multi-scale dynamic modeling and simulation, large-scale optimization, Smart Plant technologies, data interoperability, sensor networks, and scalable requirements-driven security need to be aggressively developed and shared as a foundational infrastructure for the chemical and biological process industry in the form of accessible CI applications, middleware, and tools.*

- *Competitive advantage lies with specific technical know-how and expertise for products or processes within each company AND with a shared applications and tools infrastructure that extends across companies in the industry.*

WE FOUND A WAY TO FAN THE SPARK AND SM WAS NAMED

Buoyed by the industry and academic convergence on Smart Plants, Jim Porter, Tom Edgar, and I came together for no other reason than we believed in the "cause." We committed to turning the workshop outcomes into something more than a report and were fortunately successful the very next year in 2007 with a proposal to NSF to form an Engineering Virtual Organization (EVO). However, the success of that proposal stemmed from an expanding group of thought leaders in computing. There was a key meeting, really a debate, by the CACHE trustees (industry and academic) about CI and manufacturing with a decision to support and participate in the proposal. It also cannot be understated how fortunate it was that Professor Phil Westmoreland at North Carolina State University (NCSU) was a program officer at NSF at this moment in time. Phil was the person who alerted us to the EVO opportunity that he was leading. Peggy Hewitt at Honeywell had taken over the ASM consortium leadership and joined Jerry Gipson as early and strong industry advocates.

With the 2006 NSF workshop opening the notion of 'Smart,' the first use of 'Smart Manufacturing,' appeared shortly after in a Letter of Intent (LOI) to NSF dated May 2007 about the EVO. As one can read, the basis of the term stemmed from needing a shorthand for "smart (predictive, preventive, and proactive), zero-incidents, zero-emissions manufacturing," which was a mouthful. As it turned out, the synopsis from the LOI captured a succinct description of what transpired in that 2006 workshop and proved to be more than words. Smart Manufacturing was named, and the influence of CI was instilled:

"An EVO to address smart (predictive, preventive, and proactive), zero-incident, zero-emissions manufacturing with process systems will be launched with a core group of engineers from academia, government, and industry and with cyberinfrastructure practitioners from the San Diego Supercomputer Center (SDSC) and the Texas Advanced Computing Center (TACC). Through the commitment of consortia leadership, the EVO will form by bringing the FIATECH industry consortium (65 companies and universities), the ASM (Abnormal Situation Management) Consortium (14 companies and universities), and the CACHE (Computer Aids for Chemical Engineering) Corporation (21 university and 7 industry trustees and 150-member chemical engineering departments worldwide) together with the broader Process Systems Engineering (PSE) community.

Supported as a virtual organization, this community will pursue a common objective of initiating and sustaining the development of a coordinated national R&D agenda and technical roadmap for smart manufacturing. This focused objective builds on an NSF Sponsored Workshop entitled, Cyberinfrastructure (CI) in the Chemical and Biological Process Systems: Impact and Directions, held on September 25-26, 2006. This workshop brought industry and academic experts together who collectively identified smart manufacturing as a grand challenge problem of national importance.

Smart manufacturing references the key points that (1) smart people are the most important ingredient in smart plants, (2) smart plants proactively seize opportunities to optimize operational and financial performance while preventing environmental, health, safety, and security problems, and (3) smart plants work for the good of the global enterprise. The scope of cyberinfrastructure needs includes multi-scale dynamic modeling and simulation, large-scale optimization, smart plant technologies, data interoperability, sensor networks, and requirements-driven security.

SDSC and TACC as TeraGrid sites will help develop the cyberinfrastructure requirements of the technical road map and will support the infrastructure for the EVO to operate. The successfully launched EVO will deliver (1) articulation of the value of smart manufacturing on a national scale, (2) sustained development of a national agenda through a mediated "living" roadmap process, (3) increased critical mass of an involved and aligned academic-industry community, (4) integration of CI tools and (5) advocacy of the roadmap."

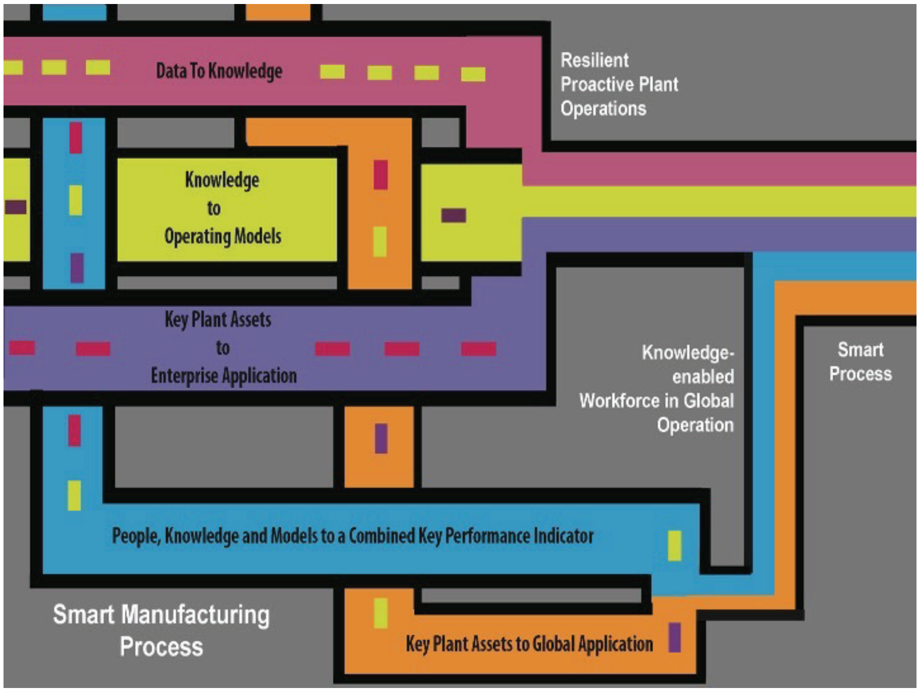
The Phase 0 SM Roadmap

The NSF grant provided funds for travel and holding a workshop, as well as developing a stakeholder-developed roadmap for the research community. Many years later, we learned that our colleagues in Germany had independently started up an analogous national manufacturing initiative under a similar tag line "Smart Factories," but in the context of a discrete part. In their case, German Chancellor Angela Merkle changed it to "Industrie 4.0," arguing it was better branding. In our case, "Smart Manufacturing" started as a label of convenience but became fixed as the name of the initiative in 2008 when the EVO was brought together to develop a Phase 0 roadmap for "Smart Manufacturing and [Environmental] Sustainability." Below is the overview graphic of the first Smart Manufacturing (SM) roadmap. The primary 'lanes' of activity are noteworthy:

- Data to Knowledge
- Knowledge to Operating Models
- Key Plant Assets to Enterprise Application
- People, Knowledge, and Models to a Combined KPI
- Key Plants Assets to Global Application

As shown, even at that time and well before any pandemic, we projected "Resilient Proactive Plant Operations" and a "Knowledge Enabled Workforce in a Global Operation." We noted shortly after that the roadmap topics were right, but the graphic depiction of lanes conveyed a linear approach, i.e., typical engineer thinking that did not adequately reflect the network, connected, and CI roots that underpinned the vision of SM.

The First Smart Manufacturing Roadmap



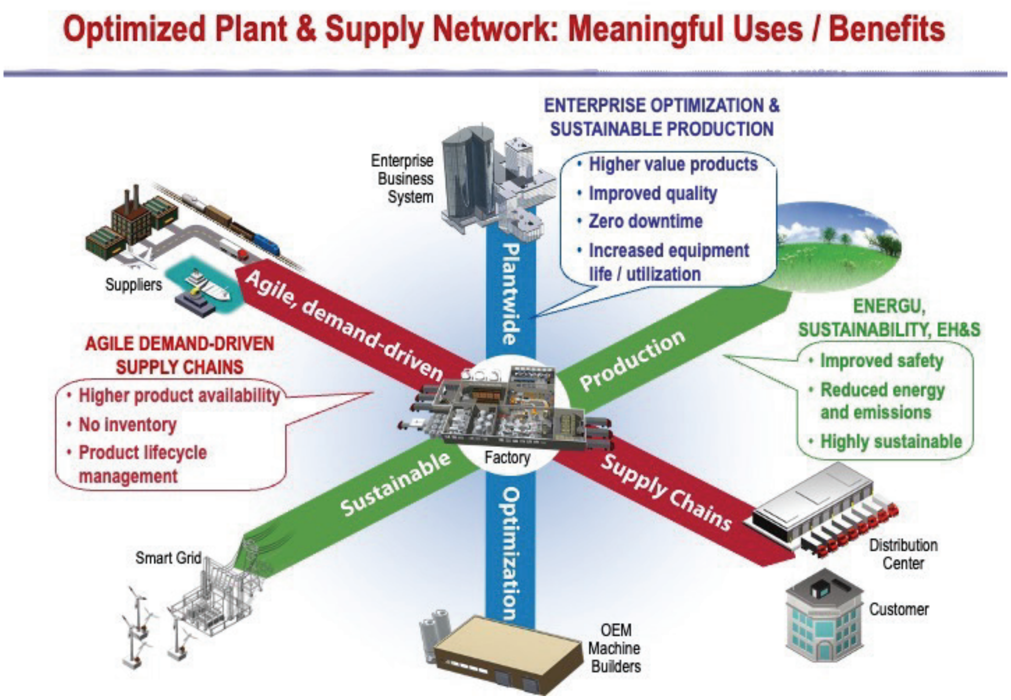
THE SMART MANUFACTURING LEADERSHIP COALITION (SMLC)

As with any initiative, timing, serendipity, and who you know continued to play major roles. In short succession, Jim Porter introduced Denise Swink to our Smart Manufacturing initiative. Denise, who retired from DOE and served on the National Academies Materials and Manufacturing Board, became our first government member. Our EVO rapidly expanded in scope to include discrete parts manufacturing after aligning with a parallel effort that John Bernaden, Director of External Communications, Rockwell Automation, had been promoting. Denise and John introduced us to Neal Elliot, Director, American Council on an Energy Efficient Economy (ACEEE), who expanded the SM effort much more deeply into its potential for reducing energy and GHG emissions.

John Bernaden's involvement further led to an introduction to Sujeet Chand, CTO of Rockwell Automation. Sujeet and I joined forces with significant help from John on an article published in the TIME Magazine in 2010 entitled, "What is Smart Manufacturing." That article included the first visual portrayal of Smart Manufacturing, a graphic attributable to Sujeet who first sketched it. Because Smart Manufacturing is about cyber and scale and difficult to convey in words, this picture far exceeded its 'worth of 1000 words' and became the best way to quickly understand the scope and scale of SM and the extent and full richness of integration on which it is underpinned. This graphical description became widely used.

The First Visual of Smart Manufacturing

(Showing that SM is Integration at Scale)



The National Discussions Launched

The timing of this SM effort unpredictably coincided with the 2007-2009 economic downturn which provoked a national discussion about global manufacturing leadership, competitiveness, and innovation. After many visits to Washington D.C. and many discussions with agency leaders with the help and support of Denise, Neal, John, and Bruce Quinn, the Federal Relations Director at Rockwell, Smart Manufacturing began to experience growing momentum as a consideration for the future of U.S. manufacturing. It became an argument for the importance of the manufacturing process itself and innovation in the ability to make things, not just invent them. A very early national connection took place in association with groundbreaking discussions about next-generation manufacturing and a digital future within the President's Council of Science and Technology Advisors (PCAST)/President's Innovation and Technology Advisory Committee (PITAC) chaired by Eric Schmidt (Executive Chairman, Google) and Shirley Ann Jackson (President, Rensselaer Polytechnic Institute). Sujeet Chand and I contributed views on Smart Manufacturing and the SMLC and our group was introduced to Sridhar Kota, Director of Manufacturing Policy for the Office of Science and Technology Policy (OSTP)[4]. Sridhar became instrumental in guiding discussions for Smart Manufacturing to be considered in the national discussions and, notably, encouraged the concept of a public-private partnership (PPP). The concept of a PPP brought out the advantage of our group's uniqueness which was extensive industrial, academic, and government involvement and an ability to work together and voice cohesive recommendations.

The EVO Needed to Organize

We did eventually need a name besides EVO. Jim Porter and Tom Edgar can take credit for the name, SMLC. Our grassroots, industry-academic-government PPP, was named the Smart Manufacturing Leadership Coalition and we became known as the SMLC. The SMLC was growing in interest, the work of continuing to develop SM was expanding, and the opportunities for national discussion were increasing. To fund meetings and member administration, the SMLC became a member-funded volunteer organization with a differentiated dues structure for companies, universities, government, and non-government organizations. Denise Swink took on the SMLC program and management leadership and Tom served as Treasurer. I started leaning on Julie Tran, a project manager in my UCLA office, who began taking on meeting and member administration, and I turned to Prakashan Korambath, a research scientist within my Office of Advanced Research Computing (OARC) organization at UCLA, for help with technical considerations.

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[4] Professor of Mechanical Engineering at the University of Michigan.

Tom turned to CACHE for financial management and grant administration. Denise organized our advocacy meetings in D.C. and workshop priorities and Julie made it possible to organize and run meetings and workshops, and importantly to engage and communicate with a growing number of members.

We were on shoestring financing and many contributed resources to bring us together to build and socialize our thought leadership typically in the form of one- and two-page position statements, brochures, and white papers. We can also thank American and United Airlines for their meeting services since there were many airport meetings. Most importantly, the SMLC was able to facilitate a format, a way of engagement, and the right tone of collaboration that was conducive to developing SM through the voice and lens of a PPP. The way the meetings were conducted, the respect held for various viewpoints, and the work products developed truly propelled SMLC forward from an industry standpoint because the SMLC meetings became a venue for forthright industry collaboration on how early SM initiatives were being championed.

Over this time, the SMLC membership continued to grow notably with Jim Wetzel, Director of Engineering Global Reliability, General Mills, who would eventually become the SMLC chair on the CESMII proposal team and later Interim CEO of CESMII; Larry Megan, Praxair, and Pete Sharpe, Emerson Process Systems, both of whom would become instrumental in an industrial demonstration of Smart Manufacturing, and Mike Sarli, ExxonMobil, who would join a group of us to write a seminal paper. There were many discussions in DC with significant churn on ideas, but some stood out, like Mike Sarli being struck by DOE mentioning that DoD was starting to worry about supply chains with computer chips, as one important example.

Efforts on legislative language, especially through the work of John Bernaden and Neal Elliot, produced draft language that facilitated government discussion. Some of this early draft language ultimately appeared in recent legislation, 15 years later. Denise, with her DOE background, helped sponsor several meetings that garnered DOE and NIST interest in Smart Manufacturing's potential impact, not only for advancing manufacturing with new business and operational technologies and new ways to innovate on products and processes, but also for reducing energy consumption and GHG emissions. As a side note, we were never quite able to achieve any branding breakthroughs. After 'Smart Manufacturing,' John and I wanted to bring the network effects into the SM picture more strongly and took a run at conceiving SM as a network of operational nodes. We even got so far as calling it a 'Network of Things.' The acronym "NOT" didn't exactly create a sense of 'next generation' manufacturing, but IoT certainly did take off shortly after and we stuck with 'Smart Manufacturing.'

THE TIME TO DO MORE THAN TALK ARRIVED

Time to Drill Down

In September 2010, the SMLC was effectively tasked with drilling down on a roadmap, and organized a workshop with sponsorship from DOE and NIST called, “Implementing 21st Century Smart Manufacturing” with the following three objectives:

- *An Actionable Program Agenda*
- *Meaningful Use Priorities & Metrics*
- *Recommendations on Public-Private Partnership Programs*

The participants included 24 practitioner manufacturers, nine suppliers, five universities, two computing centers, and five manufacturing consortia plus DOE, NIST, NSF, ACEEE, Oak Ridge National Laboratory (ORNL), and the Council on Competitiveness. The SMLC had further matured the written definition of Smart Manufacturing:

> *“Smart Manufacturing (SM) is a dramatically intensified knowledge-enabled industrial enterprise in which ALL business and operating actions are executed to achieve substantially enhanced energy, sustainability, environmental, safety and economic performance.”*

As before, there was a strong and resonating voice of the industry about what needed priority attention including the industry’s need to work with much greater collaboration. The consistency of the 2010, 2008, and 2006 workshops was remarkable. There were ten priorities identified among which was the first industry call-out for shared platform technologies. A key chart published in the report is shown below. See priority 1, which calls for community platforms, the precursor to today’s Smart Manufacturing Innovation Platform (SMIP). See priority 2, about “toolkits of software,” which are today called Smart Manufacturing Profiles. See priority 8, about an open platform and data sharing between small and medium enterprises (SMEs) and large companies.

The results of this latest workshop were published in June 2011 in a report that became not only ‘the’ plan of action for the SMLC, but also, in retrospect, a juggernaut for the next phase of the SM evolution. Discrete parts and batch operations-oriented industries had joined in supporting the findings and recommendations of the process industries resulting in the full breadth of manufacturing engagement.

The White House and the federal agencies jointly recommended that the SM community create a single entity for them to accelerate their collaborations. The work plan, itself a major product of the workshop, gained domestic and international attention and was used as the basis for engagement and planning by industry, government, and academia together, which became the set-up for a Public-Private Partnership (PPP).

Tom Edgar, Jim Porter, John Bernaden, Mike Sarli, and I subsequently wrote and presented a paper about the workshop results for a CACHE-sponsored, Foundations of Computer-Aided Process Operations (FOCAPO) conference in 2011. The paper, entitled, "Smart Manufacturing, Manufacturing Intelligence, and Demand-Dynamic Performance," was subsequently published in Computers and Chemical Engineering in 2012 and has been highly cited. This paper was ultimately referenced in the DOE NOI in 2014 (discussed later) to form a Smart Manufacturing Institute.

Ten Priority Actions for Smart Manufacturing in 2010

Industrial Community Modeling and Simulation Platforms for Smart Manufacturing			
1. Create community platforms (networks, software) for the virtual plant enterprise	2. Develop next generation toolbox of software and computing architectures for manufacturing decision-making	3. Integrate human factors and decisions into plant optimization software and user interfaces	4. Expand availability of energy decision tools (energy dashboards, automated data feedback systems, energy 'apps' for mobile devices) for multiple industries and diverse skill levels

Affordable Industrial Data Collection and Management Systems	
5. Establish consistent, efficient data methods for all industries (data protocols and interfaces, communication standards)	6. Develop robust data collection frameworks (sensors/data fusion, machine and user interfaces, data recording and retrieval tools)

Enterprise-wide Integration: Business Systems, Manufacturing Plants, and Suppliers		
7. Optimize supply chain performance through common reporting and rating methods (dashboard reports, metrics, common data architecture and language)	8. Develop open platform software and hardware to integrate and transfer data between small and medium enterprises (SMEs) and original equipment manufacturers (OEMs) (data sharing systems and standards, common reference architectures)	9. Integrate product and manufacturing process models (software, networks, virtual and real-time simulations, data transfer systems)

Education and Training in Smart Manufacturing
10. Enhance education and training to build workforce for smart manufacturing (training modules, curricula, design standards, learner interfaces)

Time to Demonstrate

Another noteworthy and serendipitous event occurred shortly after the 2011 workshop. Dean Bartles, VP at General Dynamics, and I happened to be sitting together in the large conference hall on the NIST campus at a conference on manufacturing competitiveness. The subject was innovation in technologies and products, and interestingly was not about operations and management. By chance, not only were we sitting together but the meeting format happened to include time for everyone to introduce why we were there. The chance meeting resulted in a historic alignment. Dean joined the SMLC and would later become the inaugural chair of a formalized SMLC in 2012 (and the first SMLC member to have a personalized SMLC Florida license plate).

The SMLC needed to demonstrate Smart Manufacturing and engaged in two key funded projects that became critical to SM moving forward. Dean's SMLC leadership and industry sponsorship became threshold ingredients. First, the SMLC decided to write a proposal to DOE's Industrial Manufacturing Innovation (IMI) program to do an industrial demonstration of Smart Manufacturing. There were many people involved but essential industrial leadership and participation were provided by Larry Megan and Jesus Flores-Cerrillo, then with Praxair, and Dean Bartles, then with General Dynamics. Larry and Dean sponsored two distinctly different industrial operations to be use cases for demonstrating a smart manufacturing platform that could facilitate increases in energy productivity across diverse solution requirements. The Praxair operation was a Steam Methane Reformer, which is a continuous oil and gas process. The General Dynamics operation was a metals fabrication, a discreet parts process comprised of forging, heat treating, and machining.

The SMLC was not yet a formal entity, so Tom Edgar agreed (or as he likes to say, "didn't step back fast enough") to be Principal Investigator with the University of Texas, Austin as the administrative home. We organized a like-minded group of industry providers and coalition partners for the demonstration that included Schneider Electric, Emerson Process Management, Nimbis Services, the American Institute of Chemical Engineers (AIChE), the National Center for Manufacturing Sciences (NCMS), and NIST – through an associated project. Denise Swink managed the SMLC outreach to large manufacturing and energy stakeholders.

Darlene Schuster (AIChE) and Jon Riley (NCMS) oversaw energy metrics and outreach to small and medium manufacturers. Tom Edgar, UT Austin Professor Michael Baldea, and I combined efforts on engaging considerable data and modeling capabilities through a cadre of faculty, graduate students, and research scientists at UT Austin and UCLA. The comprehensive expertise that came together was astounding.[5]

The proposal was written in 2011 but was not awarded until March 2013. In retrospect, that two-year span proved essential for defining the SM Platform and coalescing the expertise and the team. Defining, integrating, and cross-training on these different areas of expertise were key developments and experiences that have carried directly into upskilling and using the CESMII Smart Manufacturing Innovation Platform (SMIP) today. The DOE project itself was funded from September 2013 through November 2017 and significantly overlapped with the national discussions about what to do to address U.S. manufacturing competitiveness. Our DOE partners were Isaac Chan as a sponsor and Kristen McDaniel and Debbie Schultheis as our contract managers.

In terms of its larger impact, the DOE IMI project was unique in that it dealt with the SM impacts of data and modeling AND how to speed up adoption. It addressed the viability and ways for accelerating the development and adoption of technologies and systems with hands-on integration of real plant data. It brought out how to cut the cost and time to get to operational impact and how to speed up adoption with replication and reusability of data and models.

From an SMLC perspective, we were taking industry interests and industrial project results and experiences into the national discussion in “real-time.” These results also became CESMII performance requirements.

[5] UT Austin: Tom Edgar, Michael Baldea, Joseph Beaman, Ofodike Ezekoye, Ankur Kumar, Dan Wanegar, Hari S. Ganesh; UCLA: Jim Davis, Prakashan Korambath, Panagiotis D. Christofides, Vasilios Manousiouthakis; Nimbis Services: Robert Graybill, Brian Schott; Praxair: Larry Megan, Jesus Flores-Cerrillo, Gangshi Hu, Tushar Vispute; General Dynamics: Dean Bartles, Joseph Chup, Todd Albertson, Stephen Cannizzaro; Emerson Process Management: Pete Sharpe; Schneider Electric USA: Mak Joshi, Paul Hamilton, Michael MacKenzie; American Institute of Chemical Engineers (AIChE): Darlene Schuster, Lucy Alexander; National Center for Manufacturing Sciences (NCMS) Phil Callahan, Jon Riley; Smart Manufacturing Leadership Coalition (SMLC): Denise Swink

What About the Industry-Shared SM Platform?

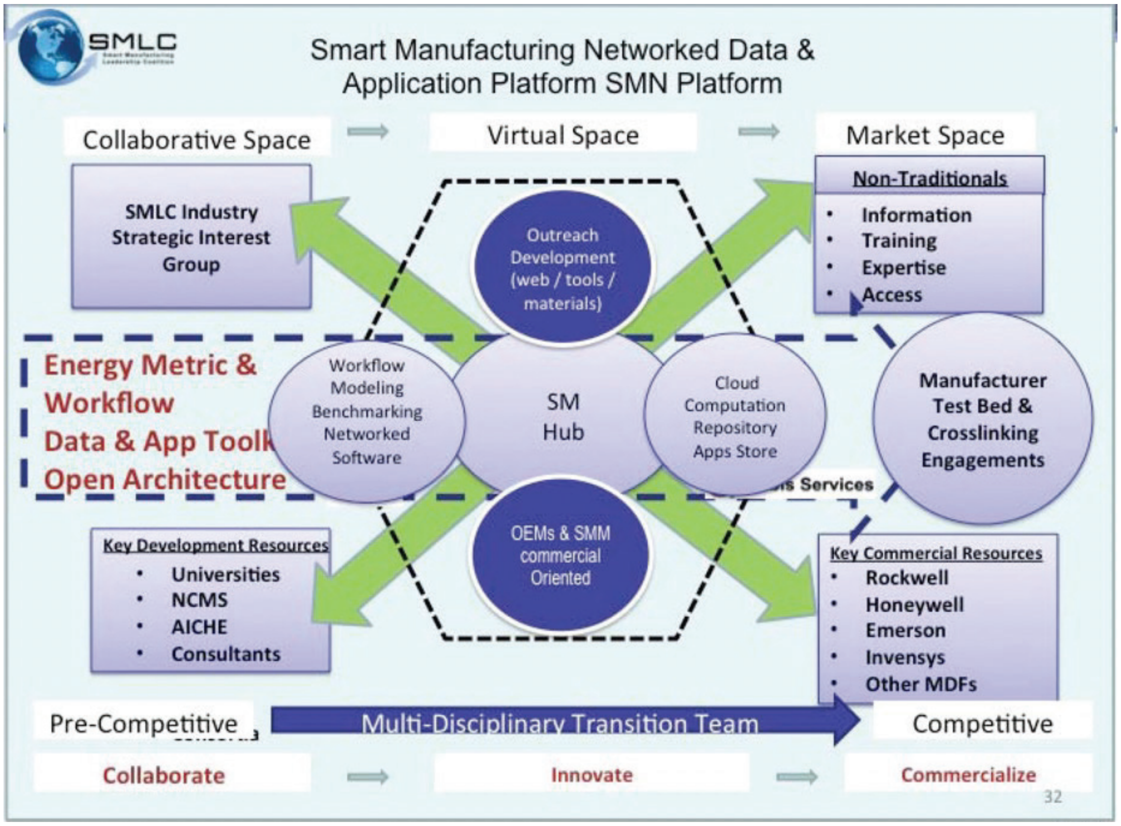
Keep in mind that the 2011 workshop resulted in significant industry buy-in to a concept of a shared industry SM platform. This represented a most interesting and atypical engineering twist in that the SM Platform was named and became a priority but had not been defined. Yet we were writing a proposal to demonstrate it. We needed to use the proposal effort to bring the SM Platform into a much clearer definition. During proposal writing, Bob Graybill and Brian Schott at Nimbis Services, Pete Sharpe at Emerson Process Management, Prakashan Korambath at UCLA, and I focused on defining the SM Platform working with Larry Megan, General Dynamics personnel through Dean Bartles, and UT Austin's Tom Edgar and Michael Baldea, who was leading the modeling team.

The concept of industry-shared SM Platform had grown from a UCLA research use case in which the analysis of protein folding required data sets to go through a sequence of analyses that could only be performed by different research groups with different software tools at different universities. A shared platform for orchestrating the data, the data transformations, the software, and the analyses made it possible to accelerate protein folding characterizations from months to weeks. This experience prompted a focus on building the platform to accelerate the development, testing, and implementation of orchestrated data and modeled systems by reducing the time and effort to do all the data, software, and system integrations and orchestrations. This included making as much reusable as possible for the next implementation.

We had the benefit of the paper written about the 2011 workshop where we had published the first rendition of a Smart Manufacturing platform for the manufacturing industry.[6] Jon Riley at NCMS had sketched an early version for Digital Manufacturing (see below). This was the rendition used in the DOE IMI proposal. In 2012, Howard Harary, NIST's Director of the Engineering Laboratory, received a separate SMLC proposal that I had written to NIST to prototype a metric and workflow architecture for a Smart Manufacturing Platform. The proposal was reviewed favorably and the NIST project provided the kickstart to a much more detailed functional specification. Also, Jim Wetzel provided a General Mills farm-to-fork supply chain problem in the manufacture of Cheerios that we used as a third industrial use case to develop the specification of the SM Platform for supply chains.

[6] This view of the SM Platform was adopted from a visual structure attributable to Jon Riley at the National Center for Manufacturing Sciences who sketched the structure for some digital manufacturing concepts.

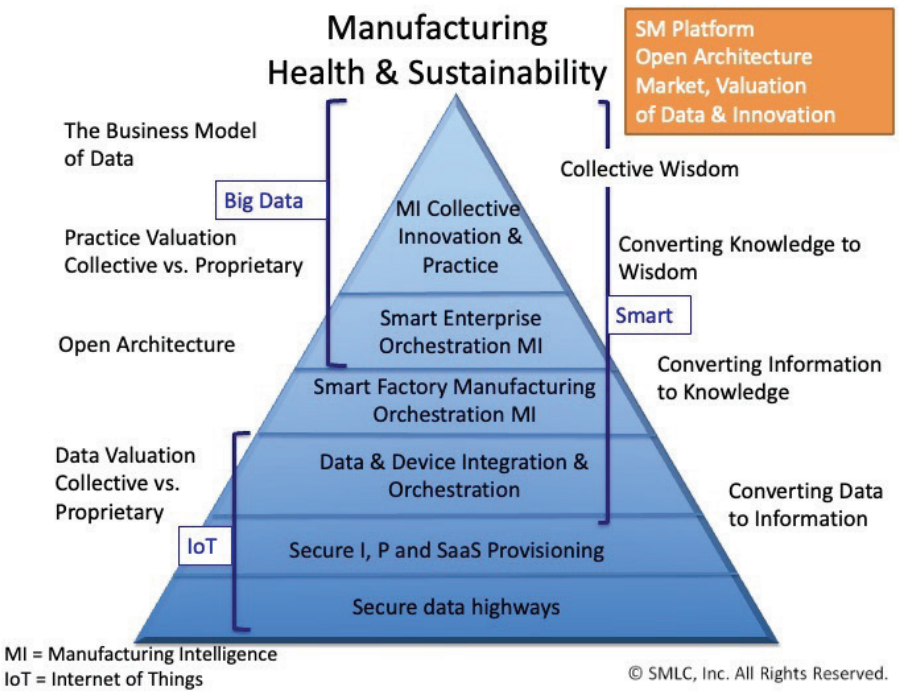
The First Rendition of the SM Platform



This supply chain use case became an SMLC lighthouse project before the Praxair and General Dynamics demonstrations were underway. Once all three were in development, having industrial demonstrations for a continuous energy-intensive oil and gas process, an energy-intensive discrete parts manufacturer that used machine tools extensively, and a food industry supply chain management process provided a significant opportunity to build the SM Platform for cross-industry applicability and scale.

In taking the first rendition of the SM Platform forward, the NIST work[7] produced a chart that portrayed the operational role of the SM Platform as shown below. This NIST work was synced with the DOE project and the chart was used extensively in the national discussions. By the time we got to the industrial demonstrations in the IMI project, we had a team with expertise in the two domains, modeling, data acquisition, control, energy management, and the Platform all cohesively together. Given the range of industrial use cases we had to work with, engaging SM Platform development at the Smart Factory and Smart Enterprise layers and working down the pyramid became a strategy decision.

The First Operational Portrayal of the SM Platform



How the platform could also facilitate development collaboration and not just technology had also become clear, and we needed a workflow tool to demonstrate orchestration. Because it was open source, the Kepler toolset became the demonstration environment of choice with Prakashan Korambath already our resident expert.

[7] Guided by the involvement of Evan Wallace, Frank Riddick and Serm Kulvatunyou at NIST

Bob Graybill and Brian Schott at Nimbis and Prakashan gave life to the specification of the SM Platform defined in the NIST project. Developing and managing this integrated domain, modeling, application, instrumentation, platform, and IT expertise proved key. It also generated additional insights on how to use the SM Platform across companies not only for operations but when building models and systems. We were able to demonstrate several key platform functionalities with a prototype.

The interactions with NIST also plugged our SMLC efforts into a series of workshops and discussions that NIST was leading. It was through these workshops that we met and began to work with Sudarsan Rachuri who was leading NIST Programs in Sustainable Manufacturing, the Smart Manufacturing Systems Design, and Analysis[8]. Four years later, Sudarsan became the DOE Program Manager for the CESMII Institute. Bruce Kramer, Senior Advisor at NSF, was also involved with several of these workshops and introduced several key perspectives about dealing with increasing complexity in manufacturing.

THE SMLC AND THE NATIONAL DISCUSSIONS

In 2011, President Barak Obama formed the Advanced Manufacturing Partnership Steering Committee, referred to as AMP 1.0, a committee of industry, academic, and government experts tasked to make recommendations on what the U.S. should do to re-capture domestic manufacturing competitiveness. The AMP 1.0 report was released in July 2012 and recommended the formation of a National Network of Manufacturing Innovation Institutes (NNMIs) as public-private partnerships to foster regional ecosystems in advanced manufacturing technologies. Two "digital" areas that took the form of acronyms were explicitly called out (these two acronyms soon became important):

- Advancing Sensing, Measurement, and Process Control (ASMPC)
- Visualization, Informatics, and Digital Manufacturing Technologies (VIDM)

In this same timeframe, the SMLC was still an informal organization, but we realized that we needed to become an "entity" for credible participation in the national discussions and to be able to take on initiatives. The SMLC became a 501c6 nonprofit corporation in November 2012. Dean Bartles became the inaugural Chair of the Board, Denise became the CEO, Tom became Treasurer, and John and I filled out the Executive Committee.

[8] https://www.nist.gov/system/files/documents/2017/05/09/SMSDAFY2014.pdf

This timing couldn't have been better if it were planned. Funding materialized through DOE in 2013 for the IMI program and the SM demonstration project was awarded to the SMLC, which was now positioned as a partner entity. President Obama launched the Advanced Manufacturing Partnership Steering Committee 2.0 (AMP 2.0) in September 2013 to focus on high-quality manufacturing jobs and enhancing America's global competitiveness. The Revitalize American Manufacturing and Innovation (RAMI) Act of 2013, which authorized the formation of the National Network of Manufacturing Innovation Institutes (later named the Manufacturing USA Institutes), was passed in 2014.

The SMLC continued to grow in membership and strengthen industry voice and recognition. Dean Bartles, Jim Wetzel, and John Bernaden's industry leadership had become more and more significant, and Michelle Pastel from Corning Incorporated and Haresh Malkani from Alcoa had now also joined the SMLC. Additionally, Alcoa had actively engaged not only through Haresh Malkani but also Lance Fontaine and Doug Ramsey. Alison Gotkin with United Technologies Research Center entered the discussions. There were multiple SMLC workshops across two key years but four were of note, with Jim Wetzel, Michelle, Haresh, and Tom each sponsoring a key industry-oriented workshop. In short succession, the SMLC held a workshop in Minnesota, one at Corning's Headquarters in New York, one at Alcoa Corporate Headquarters in Pennsylvania, and one at the UT Austin President's conference room. These were high-profile workshops in which the SMLC was able to bring out the voice of industry and at the same time tie in DOE and NIST project results literally as they were unfolding. These workshops stood out because the agendas were centered on industry practitioners discussing in some detail what SM meant to their respective companies and how they were championing digitalization efforts. All four workshops significantly spurred the interest and potential for SM Platform capabilities with early demonstrations by Bob Graybill, Brian Schott, Pete Sharpe, and Prakashan Korambath working on the Praxair, General Dynamics, and General Mills use cases plus additional use cases with Alcoa and Corning.

This was a critical period for the SMLC. General Mills, Alcoa, and Corning were able to describe related industrial interests. Mark Besser from Savigent (now Symphony AI), in supporting the SMLC but keeping us grounded, stepped in with important and impassioned cross-industry viewpoints at these workshops on business, markets, and what the SMLC needed to address for an SM Platform to be viable. There were many others involved with the SMLC (on the order of 60 companies and institutions).

Quite a few of the people involved in this phase of the SMLC proved not only to be instrumental in moving SM forward but they also became key to translating and defining SMLC developments into the future CESMII.

Jim Wetzel, Michelle Pastel, Denise Swink, and I were members of the oral defense team for the CESMII proposal to DOE. Jim Wetzel went on to be the Chair of the SMLC and then CEO of CESMII. Haresh Malkani became the CTO of CESMII, and Michelle became the Chair of the SMLC while CESMII was starting up. Denise continued as CEO of SMLC throughout. Mark Besser, Michelle Pastel, Bob Graybill, Howard Harary, Jesus Flores-Cerrillo, Alison Gotkin, Sudarsan Rachuri (as DOE program manager), and I are all currently on the CESMII Governance Board. Doug Ramsey and Lance Fontaine have remained active as key advisors and advocates for Smart Manufacturing in the U.S. and internationally.

We are ahead of ourselves, however. With the SMLC a formalized non-profit, armed with a growing industry voice and focus, several of us participated directly in the AMP 2.0 discussions. The AMP 2.0 report was released in October 2014. At that time, the Digital Manufacturing and Design Innovation Institute (DMDII), which became MxD, had already been announced in February 2014 as an NNMI sponsored by the Department of Defense. The AMP 2.0 report called out Advanced Sensing, Control and Platforms for Manufacturing (ASCPM) along with Visualization, Informatics, and Digital Manufacturing (VIDM) as key technologies. Of note, the report went on to recommend establishing Manufacturing Technology Testbeds to demonstrate the use of and business case for new technologies including “smart manufacturing” capabilities, and to recommend a new NNMI focused on ASCPM for energy use optimization in energy-intensive and digital information-intensive manufacturing. An interesting artifact of the discussions is that because the AMP 1.0 report had created the acronym ASMPC (Advanced Sensing Measurement and Process Control) there was interest in finding a way to use a similar acronym to keep the two reports related. The acronym ASCPM (Advanced Sensing Control Platforms and Modeling) was born recognizing the role of “platforms.”

It was this AMP 2.0 report that linked Smart Manufacturing and ASCPM and launched the national discussion about Smart Manufacturing as a possible NNMI. Neal Elliott from ACEEE had been in discussion with David Danielson, the Assistant Secretary of EERE, and Mark Johnson was just coming on as Director of the DOE’s Advanced Manufacturing Office (AMO). Additionally, around this time Neal had been working with the Senate committees on Energy and Natural Resources, and Energy and Water Appropriations, and legislation in support of SM. It was also at this point that DMDII and Smart Manufacturing became linked because of a long discussion about one institute versus two.
Tom Edgar and I organized an NSF Workshop in 2015 at Georgia Tech to evaluate the impacts of ASCPM on energy efficiency, carbon footprint, environment, and safety, and to identify the interfaces with VIDM. The workshop also dealt with semantical meanings and attributes of digital manufacturing, continuous/batch/discrete manufacturing, digital thread, and design vs. operations relative to smart manufacturing. This workshop was important in distinguishing between Smart Manufacturing and Digital Manufacturing.

While Smart Manufacturing and Digital Manufacturing Design Innovation did need to integrate, there was a prevailing sense that the space of development and practice was so large for each that making faster progress warranted two institutes. Our own Dean Bartles left the SMLC to become CEO of DMDII and Jim Wetzel took over as Chair of the SMLC. There was a list of distinctions between Smart Manufacturing and Digital Manufacturing that were later developed.

A SMART MANUFACTURING INNOVATION INSTITUTE BECAME A REALITY

The Department of Energy responded to AMP 2.0 and facilitated further national discussion out of which several priority areas were considered. Secretary Ernest Moniz mentioned Smart Manufacturing in testimony to Congress in response to questions from Senator Jeanne Shaheen who was on the Senate committees mentioned above. There was a multi-topic workshop in October 2014 that included a discussion about Smart Manufacturing and Process Intensification. It was at this meeting that we (the SMLC) met Mike Rinker, then Market Sector Manager of Energy Efficiency and Renewable Energy, and Suresh Baskaran, then Chief Science & Technology Officer, Energy & Environment Directorate from Pacific Northwest National Laboratory. Mike and Suresh became core partners on the CESMII proposal team about a year later and Mike became an instrumental member of both the proposal and the oral defense teams.

DOE ultimately decided to issue the NOI in November 2014 to form a Clean Energy Smart Manufacturing Innovation Institute. Please see the first two pages below. They tell us about the expected impact of Smart Manufacturing and list the features expected to be key. The AMP 2.0 report and the multi-topic meeting are both referenced. Notably referenced is our 2012 paper, “Smart Manufacturing, Manufacturing Intelligence, and Demand Dynamic Performance.” Our DOE demonstration project must have had a positive influence on the prospects of a Smart Manufacturing Institute. The acronym ASCPM was extended to ASCPMM (Advanced Sensing, Controls, Platforms and Modeling for Manufacturing) and Smart Manufacturing was tied to reducing energy consumption and GHG emissions, which had been raised as a priority in the original 2006 NSF Workshop. These objectives became objectives of the DOE IMI project.

This NOI was a milestone that established Smart Manufacturing as a national initiative and U.S. priority. It bookended nearly a decade of effort that started when the Internet and cyberinfrastructure were new in 2005-2006 and “Smart Manufacturing” was first used to describe a scaled and expansive, industry-wide approach to operational interoperability. These ‘origins’ of Smart Manufacturing were forged from the efforts of a remarkable and persistent industry, academic, and government leadership group that was a true grassroots public-private partnership.

The Notice of Intent for A Smart Manufacturing Institute

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Notice of Intent (NOI)

Notice of Intent No. DE-FOA-0001262

Notice of Intent to Issue
Funding Opportunity Announcement No. DE-FOA-0001263
"Clean Energy Manufacturing Innovation Institute on Smart Manufacturing: Advanced Sensors, Controls, Platforms, and Modeling for Manufacturing"

The Office of Energy Efficiency and Renewable Energy (EERE) intends to issue, on behalf of the Advanced Manufacturing Office (AMO), a Funding Opportunity Announcement (FOA) entitled "Clean Energy Manufacturing Innovation Institute on Smart Manufacturing: Advanced Sensors, Controls, Platforms, and Modeling for Manufacturing."

BACKGROUND: This FOA supports the establishment of a "Clean Energy Manufacturing Innovation Institute on Smart Manufacturing: Advanced Sensors, Controls, Platforms, and Modeling for Manufacturing." Smart Manufacturing represents an emerging opportunity faced broadly by the U.S. manufacturing sector to merge information and communications technologies with the manufacturing environment for the real-time management of energy, productivity, and costs in American factories all across the country. Smart Manufacturing was recently identified by private sector and university leaders in the White House's Advanced Manufacturing Partnership 2.0 as one of the highest priority manufacturing technology areas in need of federal investment.[1] AMO held a Multi-Topic Workshop in October 2014 that included discussion about Smart Manufacturing.[2] With this Smart Manufacturing Innovation Institute, EERE seeks to develop, demonstrate, and transition to industry advanced sensing, instrumentation, monitoring, control, and process optimization using both advanced hardware and software platforms, as well as real-time and predictive modeling and simulation technologies, for industrial automation.[3] The Smart Manufacturing topic addresses the development of affordable advanced industrial data collection sensors that monitor each stage of the manufacturing process, with particular interest in sensors that can operate remotely and in high temperature, high pressure environments for real-time in-situ monitoring of manufacturing processes; control systems and data analytics that utilize advanced algorithms for pervasive low cost monitoring, control, and process optimization; industrial community modeling and simulation platforms; and technologies that enable enterprise-wide integration to reduce energy use and greenhouse gas emissions (GHG) from manufacturing. Smart Manufacturing is also central to the implementation of big data and analytics for decision support in manufacturing enterprises.[4] Significant operational efficiency and productivity improvements in processes will be the focus of this effort as these technologies would provide enabling capability for the

[1] President's Council of Advisors on Science and Technology, "Accelerating U.S. Advanced Manufacturing," October 2014.
[2] http://energy.gov/eere/amo/downloads/manufacturing-innovation-multi-topic-workshop
[3] M. Bryner "Smart Manufacturing: the Next Revolution" Chemical Engineering and Processing, AIChE (Oct 2012) 4-12.
[4] S. Qin "Process Data Analytics in the Era of Big Data" AIChE Journal 60, 9 (2014) 3092-3100.

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dynamic management of energy and material resources in manufacturing.[5,6] While many Smart Manufacturing technology elements exist in some form and level of maturity today, the scale of the required industry collaboration and development needed for Smart Manufacturing technology integration, open and interoperable platforms, and widespread cost-effective adoption of these technologies is beyond the scope of individual private sector organizations (particularly for small- and medium-sized enterprises).

Continued rapid development and accelerated deployment of Smart Manufacturing technologies and platforms into the U.S. manufacturing enterprise will result in a significant positive impact on the U.S. economy and the overall state of domestic manufacturing, while reducing energy consumption and greenhouse gas emissions (GHG) in energy-related manufacturing industries and creating new business opportunities.

Areas of interest for this FOA may include, but are not limited to, the following:

- Advanced sensors to monitor each stage of manufacturing, including sensors suitable for withstanding high temperature, high-pressure environments or sensors with embedded knowledge that makes them smarter and easier to integrate into sensor networks employed in manufacturing. Robust sensors have potential application in harsh, energy-related manufacturing processes.

- Control systems and data analytics, including 1) algorithms for real-time control and performance optimization; 2) sensor network strategies to enable pervasive low cost monitoring and control; and 3) advanced sensor analytics to capture, manipulate, fuse, and display the collected sensor data to provide the operator options for process improvement and control.

- High fidelity real-time and predictive modeling and simulation of advanced manufacturing processes and data analytics; accurate and robust mathematical models are needed to simulate advanced manufacturing processes and enable complex control algorithms.

- Application toolkits, or apps, for workflow design, process monitoring, and big data analysis for factory and enterprise wide real-time decision support.

- Open-architecture, open-standard, and open-source (when possible) software and communication platforms to enable plug-and-play connectivity to ease integration and customization across Smart Manufacturing components, different manufacturing requirements, and the latest IT hardware and standards.

[5] J. Davis, T. Edgar, J. Porter, J. Bernaden, M. Sarli "Smart Manufacturing, Manufacturing Intelligence and Demand-Dynamics Performance" Computers and Chemical Engineering, 47 (2012)145-156.
[6] J. Wassick "Enterprise-wide optimization in an integrated chemical complex" Computers and Chemical Engineering, 33 (2009) 1950-1963

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SEVEN YEARS LATER

The New Guard and the Old Guard Mix

From the perspective of the SMLC, the NOI kicked off an internal SMLC competition about different teams and themes for developing a proposal and how to set up an institute. One key concept led by Denise Swink and Mike Rinker was the formation of Regional Manufacturing Centers. Craig Dory, representing RPI and a Northeast Region, and Dean Schneider from Texas A&M and representing a Gulf Coast region, had joined the SMLC and became key representatives on the CESMII proposal development and oral defense team. Professors Paul Cohen and Phil Westmoreland (who pointed us to the original NSF EVO opportunity) from North Carolina State University, represented a Southeast Region, and Mike Rinker from Pacific Northwest National Laboratory (PNNL) formed a Northwest Region.

UCLA, the Los Angeles Mayor's Office, several of California's congressional and state legislative offices, Ellah Ronen and Lisa Cleri Reale with a business organization called LA n Sync through the Annenberg Foundation in Los Angeles, the State of California, Jim Watson who heads the California Manufacturing Technology Consulting (CMTC), our California Manufacturing Extension Partnership (MEP) organization, Professor Azad Madni at the University of Southern California, who helped us tell the CESMII story, GP Li and Richard Donovan at UC Irvine, Mark Goodstein, an entrepreneur in Pasadena, and Steve Prusha, Steve Wall, and Steve Cornford at JPL, which also provided massive proposal development capacity together with PNNL, all rallied with the SMLC around the concept of a Smart Manufacturing Institute headquartered in Los Angeles, co-located with a West Coast Regional Manufacturing Center at UCLA. These five Regional Manufacturing Centers were the precursors to today's Smart Manufacturing Innovation Centers (SMICs) of which there are now seven.

Our SMLC proposal team was formed, and a large proposal development effort was off the ground on a two-year journey that was not for the faint of heart. The effort persevered and ultimately proved successful. One notable decision along the way was on the name of the Institute. We were certain we would need a clever name. To buy time to do this, we created a temporary name by inserting the word "smart" into DOE's name for their NNMI initiative, which they had called 'Clean Energy Manufacturing Innovation Institutes' (CEMIIs). The name "CESMII" was born as a placeholder and stuck as a pronounceable acronym as the name of the Smart Manufacturing Institute that would be focusing on ASCPM (Advanced Sensing Controls Platforms and Modeling) for Manufacturing. Perhaps coincidence, we note that the plays with the ASCPM acronym continue. An annual conference for the semiconductor industry has been branded APCSM 2022 where the acronym stands for "Advanced Process Control Smart Manufacturing."

An entire book can be written on the proposal process that took place over the next two years. However, the most succinct statement is that the proposal was written and defended between December 2014 and December 2016, and everyone lived. CESMII was officially started in December 2016 and is now in its fifth year as a program within my Office of Advanced Research Computing (OARC) at UCLA. Five years later, CESMII's current leadership, John Dyck, CEO; Haresh Malkani, CTO; Howard Goldberg, COO; Robin Cover, CFO (previously Cory Smith, currently at UC Irvine); Dale Turner, VP SM Innovation Center Network; Jonathan Wise, VP Technology; Conrad Leiva, VP of Workforce and Ecosystem Development; Miguel Corcio, Director of Technical Programs; Steve Winski, VP Business Development; and Jillian Kupchella, Director of Marketing (previously Mike Yost) are carrying smart manufacturing forward for the membership with an indescribably outstanding and integrated UCLA CESMII/OARC team[9] and the directors[10] and staff at seven Smart Manufacturing Innovation Centers (SMICs) and three support Satellites. As Principal Investigator, I have the luxury of working with and overseeing this strikingly effective UCLA CESMII/OARC team that has also found a true institutional home within OARC and has integrated operationally with UCLA's Federal and State Relations, Research Compliance, Purchasing, Academic Planning and Budget, Real Estate, Technology Development Group, Campus Human Resources, Campus Security, the Office of the Chief Privacy Officer, and the Dashew International Center. Marcia Smith, Associate Vice Chancellor, Patti Manheim, Contracts and Grants Director (now retired), Evan Garcia, Contracts and Grants Officer, and Tracy Fraser, Senior Director, and an army of staff in the Office of Research Administration have and continue to play very large roles. At last count, nearly 75 campus individuals are engaged in the administration of the Institute.

The CESMII and UCLA partnership is only one key partnership. It is the fact that CESMII is a public-private partnership that makes the Institute viable and its national impact possible. This structural concept of a public-private partnership (PPP) was core to the origins of Smart Manufacturing which grew out of industry, academia, and government working together. The PPP is core to how the NNMIs were set up, and it remains core because Smart Manufacturing is an industry strategy. There is no Institute without what has become highly integrated, essential, and longstanding partnerships with:

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[9] David Corcio, Membership Manager; Prakashan Korambath, OARC Scientist; John Lee, Analyst; John Louka, Applications Engineering; Jose Martinez, OARC/CESMII HR; Michael Maziarz, SMIC Operations Manager; Olivia Morales, Solutions Architect; Liz Morin, OARC Accounting; Tracy Nguyen-Phan, CESMII/OARC Fund Manager; Raminder Sandhu, Program Manager; Ashley Love-Smith, Program Manager; Tara Stewart, Membership Coordinator; David Wickman, Software Development Manager; Stella Zhu, OARC Purchasing

[10] Jose Anaya, El Camino Community College (Satellite); Ragu Athinarayanan, Purdue; Nick Barendt, Case Western Reserve University; Panagiotis Christofides and Xiaochun Li, UCLA; Craig Dory, RPI; Karl Haapala, Oregon State (Satellite); John Keyes, Feyen Zylstra; Yuan-Shin Lee, NCSU; Sherri McCleary, Penn State New Kensington; Rob Schoenthaler, ThinkIQ (Satellite)

- The 153 CESMII industry, academic, government, and non-profit members who have done the heavy project lifts, and the other work of the Institute (Standing Committees, Working Groups providing feedback, etc.) with the CESMII/DOE team.

- DOE – Kate Peretti (Technical Partnerships), Bill Prymak (Project Officer), Sudarsan Rachuri (CESMII Program Manager), Julie Anderson (Legal), Geoff Walker (Contract Manager), Steven Shooter (Fellow), Emmanuel Taylor, William Handy, Shaina Aguilar, and the contracting office (also recognizing the past involvement of Mark Johnson, Rob Ivester, Valri Lightner, Mike McKittrick, Kristen McDaniel, Mahesh Mani, Brian Hunter, and Kristen Cadigan).

- An engaged CESMII Governance Board[11] chaired by Ken Creasy from Johnson & Johnson, our executive committee that includes Katherine Cahalane, Bennit AI, Mark Besser, Symphony Industrial AI, John Dyck, and me, and our full Board comprised of CESMII members including several past SMLC members, Sudarsan Rachuri from DOE, and Howard Harary, retired from NIST.

- UCLA's Executive Leadership – the Chancellor, the Provost, and Executive Vice Chancellor, the Vice-Chancellor Research and Creative Activities, and the Vice-Chancellor of Administration who joined me in supporting CESMII's mission and UCLA as CESMII's administrative home.

- The UCLA, CESMII Headquarters (HQ), and Los Angeles area community partnerships with the Los Angeles Mayor's Office (with Ricardo Vazquez, now Rob Fisher on the Board); the L.A. business community; El Camino Community College; Los Angeles City College; California State University, Northridge; and California Manufacturing Technology Consulting (CMTC) California's Manufacturing Extension Partnership program office.

These are the partnerships that have come together to position Smart Manufacturing for its next chapter. CESMII has developed exceptional robustness as a Public-Public-Private-Public-Private Partnership. I urge you to read, "The CESMII Story," by Haresh Malkani, February 2022, with an Introduction by John Dyck and a short Smart Manufacturing Introduction by me.

[11] CESMII Governance Board - CESMII – The Smart Manufacturing Institute

CESMII is looking forward to the next “10-year” chapter as a key priority for U.S. advanced manufacturing competitiveness and one of manufacturing’s key responses to environmental sustainability. And so is the SMLC, which transformed itself and continues under Advanced Manufacturing International within the Manufacturing Technology Development Group (MTDG) for which Dean Bartles is President and CEO.

Some Long-Haul Observations

AN OPTIMISTIC OUTLOOK AT A DIFFICULT PROBLEM

What a remarkable 15-yearlong ride with a remarkable group of like-minded people who have become remarkable friends and colleagues! One of the most important demonstrations has been how a public-private partnership that involves industry, academics, and government together can make things happen. It is, I believe, the key structure that is essential to Smart Manufacturing’s full impact on the industry in the U.S., which places very high value on market-driven sustainability. The greatest opportunity for Smart Manufacturing for the planet is still to come!

In projecting the future, the SM opportunity remains huge. We have only scratched the surface of what we know is possible with factories, supply chains, and ecosystems and using the network as an industry. What we don’t know yet is equally enticing. The early concepts of data as an asset established SM as an information-driven, collaborative orchestration of business, physical, workforce, and digital processes within plants, factories, and across entire value chains. Networked interconnectedness and the cyber-side data and modeling offer extraordinary untapped opportunities that are still being defined. One of the most transformative acknowledgments over the past decade is that business transformation is the limiting step today. Ten years ago, business side changes were very difficult discussions. Today, many of the opportunity questions that motivated Smart Manufacturing in the 2006, 2008, and 2010 workshops are being revisited with greater optimism for defining new business models and pathways forward. We must accelerate to keep up. We know how to monetize. We don’t know how to scale.

Over the past two years, I was pleased to co-chair[12] a three-workshop Symposium sponsored by NSF and NIST to make recommendations for the national advanced manufacturing plan[13]. The Symposium was entitled, "Strategy for Resilient Manufacturing Ecosystems through Artificial Intelligence," and brought today's industry, academic, and government experts and perspectives together. There was again (ten years later) a resolute need for industry-wide strategies, new network business models, and wide industry adoption for scaled data and know-how application to achieve the full economic, competitiveness, and environmental potential of scaled digitalization and Smart Manufacturing. This time, though, the need for business transformation was strongly acknowledged with recommendations heavily focused on addressing 'low-hanging fruit' opportunities, aligning training with tools for business and operations, and accelerating an adoption cycle across all industries. There is a particular emphasis on the digitalization of the many thousands of small and medium companies, which are critical sources of data, know-how, and innovation, and without which supply chain and ecosystem benefits are not possible. Importantly, the recommendations address a need for scalable successes, an overwhelming need to build business trust in new ways, and the need to get out of past physical side business approaches that are making digitalization more and more difficult.

Ten years later, we are far better able to articulate as an industry how managing from the factory floor to the supply chain opens the door to new precision product markets, better material availability, and enhanced end-to-end quality assurance. We can describe how new business opportunities emerge, and how workforce innovation can be unleashed in unprecedented ways. We are in a far better position to describe how best practices and know-how are embedded in our data making it so valuable, and how we can learn better from our collective data on common operations. There are now discussions about using the Internet to far greater advantage, tapping into resources – industry, university, and government – that are underused, and why it makes economic sense to do all of these. Visualization, automation, robotics, and autonomy become a progression of capability and maturity with human and machine decision-making so that resources and the workforce can be used in far smarter ways.

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[12] Stephan Biller, Incoming Professor of Industrial Engineering, Purdue and CEO and Founder, Advanced Manufacturing International; Bruce Kramer, Senior Advisor, NSF; James St. Pierre, Deputy Director, Information Technology Laboratory, NIST; together with Said Jahanmir, Exec Secretary Subcommittee on Advanced Manufacturing, NSTC; Faisal D'Souza, Exec Secretary, ML & AI, NSTC; Don Ufford, Fellow; and Lisa Fronczek, Advanced Manufacturing Program Office, NIST.

[13] See three reports:
Workshop 1: Aligning AI and U.S. Advanced Manufacturing Competitiveness, December 2020:
https://oarc.ucla.edu/sites/default/files/Workshop%201_%20Report_v9_03172021.pdf
Workshop 2: R&D Strategies to Scale the Adoption of AI for Manufacturing Competitiveness, June-July 2021:
https://oarc.ucla.edu/sites/default/files/Workshop2ReportFinal11102021.pdf
Workshop 3: National Priorities for Adoption of AI in Advanced Manufacturing, February 2022:
https://oarc.ucla.edu/sites/default/files/Workshop3FinalReport06272022.pdf

Over the past ten years, supply chain resilience, the need for skilled data-savvy workers, environmental sustainability, and climate change have come into much sharper focus. When fully extrapolated along all of these dimensions, SM is in every factory and becomes a macro strategy impacting (1) U.S. global manufacturing competitiveness, economic market share, and new revenue sources; (2) product and supply chain resilience; (3) essential industry-scaled strategies to address energy, resources, climate, decarbonization, safety, and contamination; and (4) scaled requirements for greater data security, privacy, and ethics for a much broader, more diverse, and more involved manufacturing and workforce base.

CONNECTING PAST AND PRESENT DOTS

There is no doubt that the earliest beginnings of Smart Manufacturing go way back to the ’60s, ’70s, and ’80s, and the Operations Technology (OT) elements with digitization, manufacturing’s transition to digital controllers, and the first surge of AI and “expert systems.” I also like to include the advent of modular and multiscale modeling when the ASPEN Project at MIT was underway eventually producing AspenTech. The Internet needed to come into being to truly motivate comprehensive, scalable U.S. strategies, which had been hamstrung up until then. While the 2006 NSF workshop may have been motivated by the Internet and Cyberinfrastructure, there was also convergence with rapidly increasing compute capacity and with modular and multiscale modeling at just the right time. Business ingredients were also in play with Enterprise Resource Planning (ERP) and the building interest in enterprise Key Performance Indicators (KPIs). Taken together, these were already poking at how real-time data about resources, operations, and quality, at scale, can open up new business and operational capabilities for making products and for dealing with safety and the environment.

Surprisingly, data are still not discussed as directly as needed. In manufacturing’s digitization phases that still carry through today, the view of data as a valuable, primary, and monetizable resource continues to lag relative to the physical side value of the equipment operations. Access to enough of the right data continues to be taken for granted. This view has and continues to promote a large legacy of software applications in which the data are embedded and therefore trapped in the function. This guarantees a precise but implicit contextualization of the data, but it also ensures that the data cannot be easily reused and effectively prevents scaled use, making digital transformation more difficult. We have also defined innovation to encompass “reinventing” cyber and physical systems in isolation for so many similar applications. This reinventing the “wheel” is extraordinarily pervasive. We are integrating infrastructure, not data, increasing our complexity, and fragmenting ourselves between the large companies that have the wherewithal to work with data and the many small and medium companies that don’t to the disadvantage of everyone.

The early work on AI and ML truly set in motion the view that data can be a key resource with considerably more value when separated from its functional handcuffs. The need for ingestion, contextualization, and orchestration of the data and the know-how to use it become core to SM. The 2006, 2008, and 2010 workshops took some large steps in acknowledging where and how to make data much more broadly actionable. SM's roots in AI, ML, modeling, applying domain know-how, enterprise thinking, and leveraging IT, provided key operational mechanisms to act with data at the interface of physical impact and at the same time scale to enterprise management. SM in effect raised the prospects of cyber and redefined manufacturing as the integration of equally required physical and cyber processes that together extend from the factory floor to the supply chain. For the physical side, there are the material and energy supply chains, workflow, material transformations, and operational orchestration within and across factories. On the cyber side, we can anticipate equally valuable 'data supply chains,' cyber and IT 'workflows,' inter and intra-factory data transformations, and operational orchestration of data and models throughout the industry ecosystem. Safety and resilience on the physical side are analogous to security, privacy, track and trace, and trade secret protection on the cyber side. People with the right interfaces can interface with cyber and physical processes through an expanding progression of human, cyber, and physical interactions. What is very different is that data can be used in predictive and discovery ways, at scale, and in time that is not at all restricted by the physical operation. These ideas have become the building blocks in the CESMII story. CESMII has taken up this cause.

Epilogue

CHRONICLING THE EVOLUTION OF SMART MANUFACTURING

It seems fitting to close with an academic observation that I had not realized until chronicling the origins of Smart Manufacturing. Over the years, Tom and I also had a predilection in our university roles toward collaborating on peer-reviewed papers about Smart Manufacturing every few years. There are many papers over 15 years, but there is one set that focused on Smart Manufacturing as the primary subject. Each paper, special issue, and compendium was written and reviewed independently, but when taken together, they effectively chronicle the evolution of Smart Manufacturing from the points of view of SMLC and CESMII from our beginning. In tracking back in time, you can see how Smart Manufacturing grew expansively to embrace and integrate within and across process, machine, supply chain, and ecosystem operations from its early process control roots.

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