INNOVATION AND FUTURE OF MANUFACTURING SPARKED BY CYBER-PHYSICAL SYSTEMS (CPS)

Teruhi Fukano

wonder-news.com

July 2015

Innovation and Future of Manufacturing Sparked by Cyber-Physical Systems (CPS)

BY TERUHI FUKANO
July 1, 2015 | Wonder News

EXECUTIVE SUMMARY

Ambitious attempts are underway to make use of Cyber-Physical Systems (CPS) in manufacturing. Nations like the U.S and Germany, which have taken the lead in CPS development, call this “Advanced Manufacturing” and “Industry 4.0”, respectively. CPS is the convergence of the physical world (including human users) and the virtual world (cyberspace) using advanced sensors and networks. CPS is the next-generation of engineered systems and intelligent decision support systems for people.

In CPS systems, the joint behavior of the “cyber” and “physical” elements of the system are critical — computing, control, sensing, and networking are deeply integrated into every component, and the actions of components and systems must be carefully orchestrated. For example, data (physical world) from embedded sensors in the machinery and equipment are analyzed in virtual modeling and/or simulations (cyberspace). This analytical data can be used for real-time monitoring, fault diagnosis and predictive maintenance for manufacturing equipment. Development of this virtual modeling requires advanced analytical methods to properly process big data collected from manufacturing equipment. It is said that manufacturing is the most difficult industry to standardize due to a wide variety of information being circulated in production sites. If deployment of CPS is introduced to manufacturing, “standardization” is inevitable in modeling and collection of data for manufacturing, production control, maintenance, etc. The wave of IT innovation started from the U.S., transforming the commerce and service industries, and is now flooding into the manufacturing domain. Development of advanced manufacturing based on CPS will be increasingly competitive among nations and companies, and has a potential to lead to new industries emerging.

Table of Contents

SMART FACTORIES: THE FACTORY OF THE FUTURE

In a smart factory, manufacturing elements such as products, equipment, workforce, and resources are interconnected by a network and allow remote monitoring and control of factory operations. These communications functions can be accommodated in a range of items, and a whole supply chain process, from the beginning to the end of production, can be visualized by the Internet of Things (IoT) and Machine-to-Machine (M2M). Smart factories allow companies to cope flexibly with changes in production plans, and allows small-lot production runs to meet individual customer requirements while still generating profits. Moreover, each process is optimized from development, manufacturing, and production control, allowing for flexible responses to changing external factors such as market needs and logistic conditions.

The massive amount of data obtained from numerous sensors installed in machinery and equipment in a factory can automatically generate performance models during normal operations from machine learning techniques. In addition, these data analytics could head off unscheduled maintenance based on the past fault data while comparing real-time data with a normal model. For example, a worker carries a mobile device and immediately inputs maintenance records and observations. Data on quality control and process states are stored in the quality inspection system, which can analyze the correlation of these two factors. Predictive maintenance will lower risks of business and economic losses caused by unplanned downtime in production lines.

Model-based optimization can improve energy efficiency of manufacturing processes and facilitate the integration of renewable generation in the grid. Optimization for choices of fuel /power use, generate or purchase decisions and integration of storage of different types can be done better than they are today. This would lead to reduction of energy consumption and carbon dioxide (CO2) emissions for manufacturing companies.

Data generated from multifarious sources are integrated into cloud-based data warehouses and can be taken out and used anytime, anywhere. With suitable visualization tools such as tablets, workers and operators could effectively grasp various indices of machinery and operations, fault mode, energy consumption, and utilization rate. Combining these data with existing systems, for example, enterprise resource planning (ERP) and supply chain management (SCM), would allow companies to manage their business in a more sophisticated form.

HISTORICAL BACKGROUND

ADVANCED MANUFACTURING IN THE U.S. ACCELERATES

In June 2011, President Obama launched the Advance Manufacturing Partnership (AMP), a national effort bringing together industry, universities, and the federal government to invest in the emerging technologies that will create high quality manufacturing jobs and enhance the nation's global competitiveness[1]. Investing in technologies, such as information technology, biotechnology, and nanotechnology, will support the creation of good jobs by helping U.S. manufacturers reduce costs, improve quality, and accelerate product development. The archetype of AMP is the Engineering Virtual Organization (EVO), a predecessor of the Smart Manufacturing Leadership Coalition (SMLC)[2], who advocated a framework of advanced manufacturing in 2009, which was released just a year after the financial crisis[3].

The AMP will provide the platform for similar breakthroughs by building a roadmap for advanced manufacturing (AM) technologies, speeding ideas from the drawing board to the manufacturing floor, scaling-up first-of-a kind technologies and developing the infrastructure and shared facilities to allow small and mid-sized, manufacturers (SMEs) to innovate and compete. The AMP is the being developed based on the recommendations of the President's Council of Advisors on Science and Technology (PCAST)[4].

Major emphasis of AMP investments are placed on: 1) building domestic manufacturing capabilities in critical national security industries, 2) reducing the time needed to make advanced materials used in manufacturing products, 3) establishing U.S. leadership in next-generation robotics, 4) increasing the energy efficiency of manufacturing processes, and 5) developing new technologies that will dramatically reduce the time required to design, build, and test manufactured goods.

---

[1] The White House, "President Obama launches Advanced Manufacturing Partnership", June 24, 2011
[2] The SMLC is a non-profit industry led coalition comprised of manufacturers, IT providers, manufacturing consortia, universities, government laboratories and agencies and regional consortia.
[3] Engineering Virtual Organization Steering Committee, "Smart Process Manufacturing" , November 2009
[4] PCAST is a group of top U.S. scientists, engineers, and a venture capitalist who make policy recommendations to the administration.

The U.S. government has been providing the R&D budget for AM with more than US$2.2 billion in every fiscal year since fiscal 2013 to the National Science Foundation (NSF), the National Institute of Standards and Technology (NIST), the Department of Defense (DOD), the Department of Energy (DOE), the Department of Commerce (DOC), and other federal agencies relating to the above-mentioned prioritized areas.

UNDERLYING CAUSE TO COMPILE ADVANCED MANUFACTURING

The focus on AM reflects a keen sense of crisis surrounding the U.S. manufacturing industry. Over the past ten years, the U.S. has lagged behind in innovation in the manufacturing sector relative to Germany and Japan in high-tech industries that employ a large portion of highly-skilled workers. In addition, the U.S. manufacturing sector has suffered from loss of employment, and trade deficits in manufactured goods, and a plunge in investments in the sector due to U.S. manufacturers shifting production overseas during this period. There are growing concerns that the loss in capacity over the last decade has impacted the nation's domestic innovation and manufacturing capabilities.

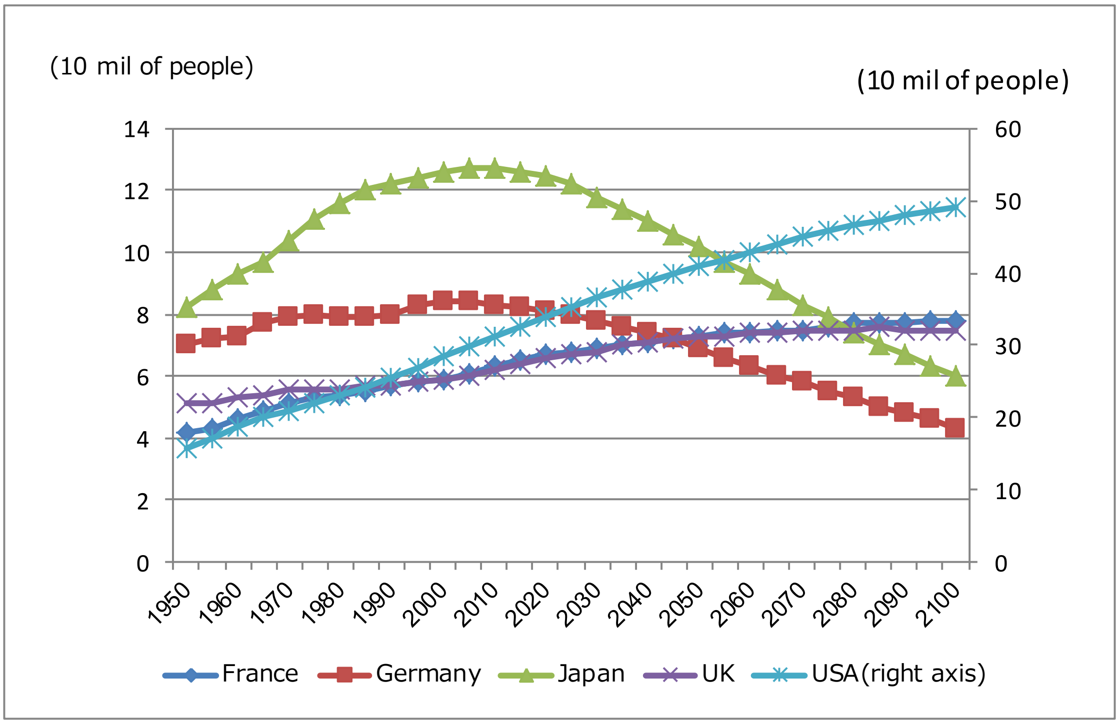
The key reasons to focus on manufacturing include 1) the sector employs millions of Americans, 2) the loss of manufacturing activities will undermine the nation's capacity to invent, innovate, and compete in global markets, and 3) manufacturing undertakes 70% of R&D in the private sector in the U.S and creates a fertile environment for innovation.

The aim of AM is to regain U.S. leadership in manufacturing through innovation. AM enables companies to shorten the production process, easily change parts and materials, and manufacture cost-effective customized products even with a small-lot production. In AM, product innovation and process innovation are different sides of the same coin. Scientific discoveries, new ideas, and novel engineering approaches can be converted quickly into the seeds of new products and processes. The country's long-term ability to innovate and compete in the global economy greatly benefits from co-location of manufacturing and manufacturing-related R&D activities in the U.S. AM is a trump card for the US to spark a renaissance in manufacturing.

INDUSTRY 4.0 OF GERMANY

The U.S. efforts evoked a sense of danger in Germany. In April 2013, the government, academia, and industry of Germany compiled and launched “Industry 4.0”. The name refers to the Fourth Industrial Revolution. The First Industrial Revolution followed the introduction of water-and steam-powered mechanical manufacturing from the end of 18th century to the 19th century. The Second Industrial Revolution started from the late 19th century and was based on electrically-powered mass production. The Third Industrial Revolution in the late 20th century used electronics and IT to achieve further automation of manufacturing. And Industry 4.0 is regarded as Cyber-Physical Systems-based technological innovation.

Figure 1
WORLD POPULATION MOVEMENT



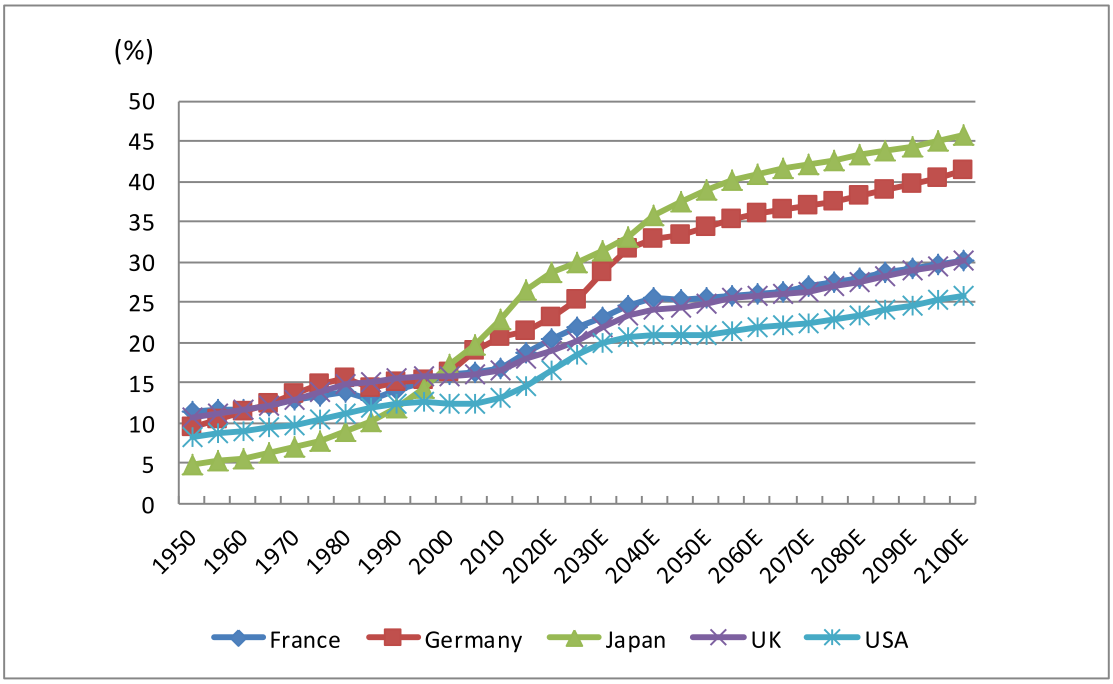
Source ： United Nations”World Population Prospects, The 2012 Revision”
(Note） Estimates are from 2015 onward.

Germany has one of the world’s leading machinery industries, and its machinery and plant engineering rank as one of the nation’s main exports alongside cars and chemicals. Furthermore, Germany's SMEs boast a strong competitiveness in manufacturing. Over 20% of Germany's top 100 small and medium-sized enterprises (SMEs) are machinery and plant manufacturers. The machinery industry has grown increasingly competitive in recent years due to emerging Asian countries catching up, alongside the long-time Japanese company rivals. If Germany allows the U.S to take the lead in advanced manufacturing, the US technologies would become de facto standards and threaten the global competitiveness of German manufacturing.

Germany is confronting an aging population and low birthrate, and has the second oldest population in the world, after Japan (Figure 1 and 2). While the average age of the workforce at many German manufacturing companies is in the mid-forties, the percentage of the workforce over fifty years old is gradually increasing. Germany will face a shortage of skilled workers after their mass retirement. CPS based Industry 4.0 could preserve and accumulate knowledge and know-how of skilled workers in the form of data and make use of them for next-age manufacturing through machine learning.

Figure 2

THE ELDERLY AS A PERCENTAGE OF TOTAL POPULATION



Source : United Nations"World Population Prospects, The 2012 Revision"

(Note 1) Estimates are from 2015 onward.

(Note 2) The elderly here means over 65 years old.

German's approach comprises dual strategies to: 1) deploy development of CPS in manufacturing, and 2) market CPS technology and products to strengthen its manufacturing equipment industry. Moreover, it is an opportunity for Germany to build a new IT security industry for automation processes, mechatronics engineering and embedded systems.

WHAT IS CPS?

Cyber-physical systems (CPS), which include critical technologies to achieve advanced manufacturing and Industry 4.0, are smart networked systems with embedded sensors, processors, and actuators that are designed to sense and interact with the physical world (including human users).

In CPS systems, the joint behavior of the "cyber" and "physical" elements of the systems is critical—computing, control, sensing, and networking are deeply integrated into every component, and the actions of components and systems must be carefully orchestrated[5].

The U.S. will deploy CPS technologies not only in manufacturing, but also in agriculture, building controls, defense, energy, healthcare, transportation and emergency response. Cyber Physical Systems Senior Steering Group (CPS SSG) plays a central role in developing the next-generation of engineered systems.

CPS SSG of the U.S and Industry 4.0 of Germany raise major strategic challenges to achieve CPS as outlined below.

- Cybersecurity
- Economics

  Improve open reference architectures and tools to reduce the cost for developing CPS systems.
- Interoperability

  The ability of CPSs to interoperate across systems in complex tasks and environment is a key challenge.
- Privacy

[5] "NITRD Supplement to the President's FY 2016 Budget"

- Safety and Reliability
  Improving reliability of CPS technologies and operational safety including low fault rate
- Sociotechnical aspects of CPS
  Success in deploying cyber-physical systems requires leveraging the interaction between people and technology, and between our complex infrastructure and human behavior

TECHNICAL GAPS OF ADVANCED MANUFACTURING

The President's Council of Advisors on Science and Technology (PCAST) specifically refers to technical gaps in the annex[6] of “Accelerating US Advanced Manufacturing” released in November 2014 as follows.

1. Open standards and interoperability for manufacturing devices, systems, and services

2. Real-time measurement, monitoring and optimization solutions of machine energy consumption and waste streams

3. Energy optimization of processes and integration with smart grids, cogeneration and microgrids

4. Health management for manufacturing equipment and systems

5. Low power, resilient wireless sensors and sensor networks

6. Integration with Big Data Analytics and Digital Thread[7]

7. Platform infrastructure for integration across heterogeneous systems

8. Software-service oriented platforms for manufacturing automation

---

[6] See more detailed description at https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports

[7] Digital Thread: advanced modeling and simulation tools to link material—design—processing—manufacturing

9. Theory and algorithms for model-based control and optimization in the manufacturing domain

10. Modeling and simulation at temporal and spatial scales relevant across manufacturing

STRATEGICALLY IMPORTANT AREAS FOR THE U.S.

Advanced Sensing, Controls and Platforms for Manufacturing (ASCPM) technologies are strategically important for manufacturing: they offer the technical elements needed in sustainability, and energy performance—and to thereby comprehensively improve the competitiveness of the U.S. factories and fulfill the goals for advanced manufacturing.

The high-priority themes among gaps of ASCPM raised by the PCAST are outlined below.

Sensing and Measurement Gaps

(1) Development of suitable sensing for manufacturing processes

(2) Cost-effective, non-invasive sensors are critically needed

(3) Real-time process analyzers with multi-sensor data fusion capability

(4) Wireless connectivity and self-contained power delivery/harvesting

(5) Knowledge-embedded smart sensor systems

Control and Optimization Gaps

(1) Theory and algorithms for control of fault-tolerant stochastic, nonlinear, hybrid systems

(2) Smart diagnostics, prognostics, and maintenance

(3) High-fidelity modeling and simulation for control and optimization

(4) Integration of process control with planning and scheduling

Platform and Framework Gaps

A smart manufacturing platform is shared infrastructure that facilitates access and actionable enterprise application of real-time networked data and model-based analytics extensively throughout the business and the operation of the manufacturing enterprise.

(1) IT infrastructure that facilitates enterprise-wide 1) integration of sensing, data and knowledge systems; 2) orchestration across heterogeneous systems; and 3) management of public and private applications and data

(2) Standardized data models and information semantics

(3) The development of models and simulations is a major challenge but an equally large challenges is the alignment of multiple models especially when developed for differing purposes—design, planning, optimization and maintenance, etc.

SYSTEM SECURITY IN INDUSTRY 4.0

A key to success in AM and/or Industry 4.0 is to ensure secured information exchanges across the whole manufacturing process. It is necessary for individual machines, processes, products, components, and materials to possess unique electronic IDs. Furthermore, it would be desirable to issue components with a kind of "security passport" containing details of the risks that were already taken into account and counteracted during development and the risks that and the risks that need to be considered by the integrator, installer, operator or user. The passports would also contain the security classification.

BIG DATA ANALYTICS

Analytics is what makes big data come alive. Analytics, comprising a number of different computational technologies, is what fuels the big-data revolution. Analytics is what creates the new value in big datasets. A brief abstract of technical gaps on big data analysis is included below[8].

(1) Data mining

Data mining refers to a computational process that discovers patterns in large data sets. Real-world data are incomplete and noisy. These data-quality issues lower the performance of data mining algorithms and obscure outputs. When economics allow, careful screening and preparation of the input data can improve the quality of results, but this data preparations often labor intensive and expense. Users, especially in the commercial sector, must trade off cost and accuracy, sometimes with negative consequences for the individual represented in the data. Additionally, real-world data can contain extreme events or outliers. Outliers may be the result of data entry or data-transmission errors. In both cases they can skew the models and degrade performance. The study of outliers is an important research area of statistics.

(2) Data fusion

Data fusion is the merging of multiple heterogeneous datasets into one homogeneous representation so that they can be better processed for data mining and management. There is a great amount of interests today in multi-sensor data fusion, generally through development of new and better algorithms, relate to data precision/resolution, outliers and spurious data, conflicting data, data correlation, centralized vs. decentralized processing, operational timing and ability to handle dynamic vs. static phenomena.

There are a number of technologies yet to be made practical for use in manufacturing. Mining of this diverse data for specific, productive uses in an automated fashion needs significant improvements for effective, real-time decision making across operations and supply chain.

---

[8] PCAST, " Report on Big Data and Privacy" , May 2014

JAPAN'S APPROACH TO ADVANCED MANUFACTURING

Unlike the U.S and Germany, Japan has largely lacked the momentum to bring together the government, academia and industry to collectively propel advanced manufacturing. According to the "Proposal for Manufacturing Process Innovation to Achieve Japanese-way of Networked Factories" provided by the Japan Society of Mechanical Engineers (JSME) in June 2014, participants from the government, academia and industry are concerned about missing the wave of advanced technology, but appear to be reluctant to introduce standardization in the manufacturing industry. A year later, in June 2015, the "Industrial Value Chain Initiative (IVI)" was formed, led by about 30 Japanese major companies from the automobile, electronics, machinery, and IT industries to promote advanced manufacturing in Japan. The reason behind this sudden swing by Japanese companies is assumed to be in response to 1) their German rivals' products based on Industry 4.0, which were displayed at the Hannover Messe, a leading trade fair for industrial technology, held in Germany in April 2015 and 2) General Electric, which has been intensely promoting its own AM products to Japanese companies. In view of the radical transformation currently underway in the manufacturing industry globally, IVI should not waste any more time and must immediately compile a roadmap and launch the Japanese-way of Networked Factories while coordinating with technology institutes.

In Japan, the National Institute of Advanced Industrial Science and Technology (AIST), develops Cyber-Physical Systems (CPS). AIST also engages in developing cutting-edge technologies in Japan including: 1) artificial intelligence generated from Big Data, 2) human factors and ergonomics, and 3) robotics.

In May 2015, the AIST made an announcement to establish an artificial intelligence center in which it will perform experimental studies using large-scale data gained from actual services in the manufacturing and service industries, focusing on research and development of artificial intelligence. Without a leadership position in these technologies, Japan will run the risk of missing the next wave of manufacturing innovation.

FUTURE OUTLOOK

Chance vs. Risks

There are many technological issues to be overcome before being able to achieve advanced manufacturing. When closely looking into each issue, we realize that AM is not a figment of the imagination, but rather has a firm position in reality. The visions the US and Germany present evoke innovation to create and secure the future of sustainable competitiveness in the manufacturing industry. AM and Industry 4.0 will progress at different rates in individual companies and sectors. While some companies have immediately launched pilot projects in their manufacturing sites, others have distanced themselves from AM and adopted a wait-and-see approach. It is said that there are four types of people; those who make a move, those who wait for a move, those who get caught in a move, and those who do not even know a move had happened. It is obvious that the fourth type is placed far from opportunity and is exposed to the highest risk.

Light and Shadow

AM will bring change to the ways of working of people, not just at production sites but all employees in the manufacturing industry. People will interact with flexible CPS based systems to perform tasks. The systems will be configured to let human users make a decision with the support of the system. Operators and engineers will, therefore, require high-level skills with a full set of IT tools. Jobs for semi-skilled workers including white-collar workers could be replaced by systems. AM will lead to increasing a highly-paid, highly-skilled workforce in the manufacturing industry. Furthermore, AM will bring about decentralized leadership and management approach to corporates. It will be necessary for companies to transform their cultures and allow employees greater freedom to make their decisions.

To train and educate the future workforce will be a key to enabling a smooth transition to AM for businesses. In the 2011 statement of President Obama, he stated that the universities[9] involved in the AMP are committed to forming a multi-university collaborative framework for sharing of educational materials and best practices relating to AM and its linkage to innovation, besides research activities and technology

[9] the Massachusetts Institute of Technology, Carnegie Mellon University, Georgia Institute of Technology, Stanford University, University of California-Berkeley, and University of Michigan

development. In Industry 4.0, Germany aims to improve lifelong learning that embraces the entire workforce, irrespective of age, gender or qualifications. The way of working, workloads management, and coexistence of people with advanced systems are all up to the choices of human users because they are the ones configuring and using the systems. If the new technologies are based on the philosophy of improving people's well-being, the future will undoubtedly change for the better.

(Writing by Teruhi Fukano; Editing by Nigel Gan)

＜BIBLIOGRAPHY＞

- ”NITRD Supplement to the President’s FY 2016 Budget”
- CPS SSG, “Cyber Physical Systems Vision Statement FY2016”,
- Dr. Jay Lee, ”Industry 4.0 and Transition to Cyber-Physical Systems Age”, December 2014
- the White House, “President Obama launches Advanced Manufacturing Partnership”, June 2011
- SMLC, “Implementing 21st Century Smart Manufacturing”, June 2011
- Smart Process Manufacturing Engineering Virtual Organization Steering Committee, “Smart Process Manufacturing”, November 2009
- PCAST, “Report to the President on capturing domestic competitive advantage in advanced manufacturing”, July 2012
- Forschungsunion and acatech, “Recommendations for implementing the strategic initiative INDUSTRIE4.0”, April 2013
- PCAST, Annex 1-10 “Transformative Manufacturing Technology: Advanced Sensing, Control, and Platforms for Manufacturing Overview”, October 2014
- PCAST, ” Report on Big Data and Privacy”, May 2014
- Japan Society of Mechanical Engineers (JSME), “Proposal for Manufacturing Process Innovation to Achieve Japanese-way of Networked Factories”, June 2014
- Advanced Manufacturing National Program Office (AMNPO), “What is Advanced Manufacturing?” See description at http://www.manufacturing.gov/advanced_manufacturing.html