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ABSTRACT: Analysts, forecasters, and many others have hailed advanced manufacturing's potential to revolutionize the American economy and drive the fourth industrial revolution. Initiatives spearheaded by the Obama Administration and the Department of Defense (DoD) seek to harness this potential. Japan and Germany likewise are making such efforts. Advanced manufacturing's potential is real; however, the Federal Government (and the DoD) must drive additional structural change, abandon outdated and unnecessary barriers, and help reform manufacturing practices and perceptions to create an environment for local and regional entities to unlock that potential. These measures can realize a competitive advantage for the U.S. economy and defense industrial base.

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Industry Study Outreach and Field Studies

On Campus Presenters

Bass Initiative on Innovation and Placemaking, The Brookings Institution, Washington, DC
Bureau of Labor Statistics, US Dept of Labor, Washington, DC
Aerospace, Defense & Government Services, The Carlyle Group, Washington, DC
Defense Logistics Agency Research and Development, Fort Belvoir, VA
Brent Scowcroft Center of International Security, Atlantic Council, Washington, DC
Asia-Pacific Security Program, Center for a New American Security, Washington, DC

Field Studies – Domestic

- Applied Rapid Technologies Corporation, Fredericksburg, VA
- National Institute of Standards and Technology, US Dept of Commerce, Gaithersburg, MD
    - Advanced Manufacturing National Program Office
    - Hollings Manufacturing Extension Partnership
    - Measurements Science for Additive Manufacturing
    - Manufacturing Robotics Test Beds
- PowerAmerica Institute (aka Next Generation Power Electronics National Manufacturing Innovation Institute), Raleigh, NC
    - Golden LEAF Biomanufacturing Training and Education Center, North Carolina State University, Raleigh, NC
    - FREEDM Systems Center, North Carolina State University, Raleigh, NC
    - North Carolina Secretary of Commerce
    - The Nonwovens Institute, North Carolina State University, Raleigh, NC
    - Phononic, Durham, NC
    - Wolfspeed, A Cree Company, Durham, NC
    - Cormetech, Durham, NC
- Air Force Research Laboratory, Dayton, OH
    - Laser Hardened Materials Evaluation Laboratory
    - Digital Thread/Digital Twin
    - Additive Manufacturing
    - Integrated Microsystems Research Facility – Trust in Design
    - Diverse Accessible Heterogeneous Integration – Emerging Electronics Reliability
    - 711th Human Performance Wing – Visual Lab: Big Data Dashboard
- Air Force Material Command, Dayton, OH
- GE Aviation, West Chester, OH
- America Makes (aka National Additive Manufacturing Innovation Institute), Youngstown, OH
    - Lorain Country Community College, Elyria, OH
    - rp+m, Avon Lake, OH
    - Sears think[box], Case Western Reserve University, Cleveland, OH
    - Carnegie Mellon University, Pittsburgh, PA
    - Swanson School of Engineering, University of Pittsburgh, Pittsburgh, PA
    - Panel Discussion – America Makes, Youngstown State University, Youngstown Business Incubator, M-7 Technologies
    - ExOne, North Huntingdon, PA
- Digital Manufacturing and Design Innovation Institute, Chicago, IL

Bunker Labs Chicago and 1871, Chicago, IL
Demonstration Factory, UI LABS, Chicago, IL
Argonne National Laboratory, Argonne, IL
Boeing, Everett, WA
Commercial Airplanes, Everett, WA and Renton, WA
Defense, Space & Security, Tukwila, WA
Advanced Development Composites, Tukwila, WA
MTorres America, Bothell, WA
Blue Origin, Kent, WA
The Museum of Flight, Seattle, WA

Field Studies – International
Mutual Defense Assistance Office, Embassy of the United States, Tokyo, Japan
Political-Military Affairs Unit, Embassy of the United States, Tokyo, Japan
Trade and Economic Policy Unit, Embassy of the United States, Tokyo, Japan
Asian Office of Aerospace Research and Development, Air Force Office of Scientific Research, Air Force Research Laboratory, Tokyo, Japan
Ministry of Economy, Trade and Industry, Tokyo, Japan
Science and Technology Policy Planning Office
National Institute of Advanced Industrial Science and Technology
Robotics Policy Office
Cross-ministerial Strategic Innovation Promotion Program (SIP), Council for Science, Technology and Innovation, Tokyo, Japan
Acquisition, Technology and Logistics Agency (ATLA), Ministry of Defense, Tokyo, Japan
FANUC Corporation, Oshino-mura, Yamanashi Prefecture, Japan
Mitsubishi Aircraft Corporation, Mitsubishi Heavy Industries, Nagoya, Aichi Prefecture, Japan

If you look at history, innovation doesn't come just from giving people incentives; it comes from creating environments where their ideas can connect." Steven Johnson[1]

The United States (U.S.) manufacturing industry enabled the "Arsenal of Democracy" in the 1940s and equipped the militaries that won World War II. The U.S. Government conceived "Rosie the Riveter," to recruit women into the industrial workforce, but she became a lasting image of American manufacturing might.[2] That same manufacturing industry drove America's post-war economic boom and provided the foundation for U.S. national security during the Cold War, with the Baby Boomer generation as its standard bearer. Since then, the U.S. manufacturing industry's impact has diminished as globalization siphoned off manufacturing jobs and the U.S. transitioned to a more services- and information technology-based economy.

Despite its struggles, U.S. manufacturing remains a critical component of the U.S. economy and national security. But, the manufacturing industry is evolving as advanced manufacturing tools, techniques, and processes—catalyzed by innovation, digital operations, and technology improvements—take hold. Dark, dingy, and dangerous factory floors employing armies of Baby Boomer laborers and assemblers are being replaced by bright, robotized, and automated centers employing a cross-disciplinary mix of designers, engineers, programmers, operators, and analysts. Currently led by Generation X and Millennial digital immigrants, these automated manufacturing centers will soon become the domain of the Digital Natives.[3]

Consequently, the U.S. and its manufacturing base are at an inflection point. This on-going transformation offers an opportunity to revitalize America's manufacturing prowess, revolutionize the American economy, and secure a strategic competitive advantage. However, at the same time, the U.S. faces challenges from an aging population, an increasing debt burden, and a strong U.S. dollar. Thus, coordinated and collaborative action by industry, academia, and, yes, government is required to seize this transitory opportunity. Together these entities, along with the Department of Defense (DoD), must drive structural change that abandons outdated and unnecessary barriers and changes manufacturing practices and perceptions in order to create an environment where local and regional entities can unlock advanced manufacturing's potential and unleash the Digital Natives' talents within the American economy.

The Obama Administration and Congress have expended significant effort on the health of America's manufacturing sector, including passage of the Revitalize American Manufacturing and Innovation Act and the creation of the National Network for Manufacturing Innovation (NNMI).[4] The NNMI's Manufacturing Innovation Institutes provide an important model for fostering the required partnerships between government, industry, and academia. The DoD's Defense Innovation Unit Experimental (DIUx) initiative seeks similar outcomes for national security capabilities. Yet, much work remains. To build upon these initial steps and secure enduring change, the Federal Government and the DoD must further enable innovation, secure the talent pipeline, and improve the business climate. The Advanced Manufacturing Team (Team AdMan) offers nine recommendations to do just this and help Rosie the Riveter become the Digital Native she is destined to become.

This report defines advanced manufacturing and then reviews current advanced manufacturing conditions, highlighting additive manufacturing and U.S., German, and Japanese innovation models. The report then provides an outlook for advanced manufacturing in the U.S followed by a discussion of opportunities to overcome innovation impediments, skills shortfalls, and business barriers along with recommendations to leverage these opportunities. The paper concludes with nine essays that delve deeper into select advanced manufacturing topics.

Advanced Manufacturing Defined

Advanced manufacturing is not an industry. Instead, it is a family of activities, that according to the President's Council of Advisors on Science and Technology (PCAST):

> (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies.[5]

With this definition in mind, Team AdMan explored the domestic and international advanced manufacturing environment, placing a particular focus on innovation centers and their nexus of government, industry, and academia (also called the Triple Helix).[6]

Among the many advanced manufacturing tools, techniques, and processes Team AdMan studied, it examined additive manufacturing as a representative example. Additive manufacturing is a process for fabricating parts layer-by-layer, by depositing layers of plastic, metal, or composite material on top of each other, directly from a 3D digital model.[7] Because the additive approach only adds the materials needed to produce the desired object, it results in less waste than traditional subtractive manufacturing approaches that remove material from a larger block to produce the desired object. In addition, it enables the ability to produce designs previously impossible to build (e.g., components with internal, contoured pathways).[8]

Team AdMan studied two main U.S. innovation resources: the recently created NNMI and the long-standing federally-sponsored research laboratories. The Obama Administration established the NNMI in 2011 to link public-private membership institutes pursuing common goals in unique concentrations. These institutes offer industry, academia, and government partners a means to leverage existing resources, collaborate, and co-invest to "nurture manufacturing innovation and accelerate commercialization."[9] The U.S. Government created the national research laboratories in the early 1940s to continue marshalling the scientific and engineering talent mobilized during World War II.[10] The labs consist of federally funded research and development corporations (FFRDC) (e.g., Argonne National Laboratory, Oak Ridge National Laboratory) as well as the military service research and development entities (e.g., Air Force Research Laboratory, Office of Naval Research).

Current Condition

Since advanced manufacturing is not an industry, Team AdMan eschewed a conventional industry analysis in lieu of a comprehensive approach to additive manufacturing. The Team examined: 1) the impact of U.S. manufacturing; 2) the diffusion and adoption of advanced manufacturing practices within the domestic industrial base; 3) U.S. government and DoD efforts to drive manufacturing innovation; and 4) Germany's and Japan's models to foster innovation. The Team concluded that advanced manufacturing tools, techniques, and processes and the NNMI institutes are generating enthusiasm, attention, and investment in pockets but that their great promise has not yet been realized in the majority of the cases.

Impact of U.S. Manufacturing

China displaced the U.S. as the largest manufacturing country in 2010. The U.S. share of global manufacturing activity declined from 28% in 2002 to 17% today.[11] U.S. manufacturing generates approximately 12% of the nation's Gross Domestic Product (GDP), or roughly $2 trillion annually.[12] Thus, U.S. manufacturing contributes almost as much to the global economy as Italy, the 10th largest economy in the world.[13] Manufacturing provides 12.3 million jobs as of 2016 (or 9 percent of the U.S. workforce),[14] down from a high of 19.4 million in 1978 and 13.9 million prior to the 2008 economic downturn.[15] Manufacturing also contributes to an economic multiplier effect providing $1.40 of GDP for every $1.00 spent, the highest of any sector.[16] In 2012, the average manufacturing worker in the United States earned $77,505 annually, including pay and benefits. The average worker in all industries earned $62,063.[17]

Despite the loss of manufacturing jobs, a prominent skills gap resulted in approximately 600,000 manufacturing jobs remaining unfilled in 2011.[18] Manufacturing industry efforts to develop a competency model, intended to decrease the skills gap and better match employees to employers, produced four separate competency models with four different required skill sets.[19] As a result, the industry sent a confusing message to educators and potential employees and exacerbated already difficult curriculum and workplace skills development challenges, respectively. Adding to the problem, manufacturing is still viewed as a "dirty, dark, and dangerous career path with jobs that require little thinking and little in the way of personal growth."[20]

Based on this information, Team AdMan concluded that manufacturing continues to play a critical role in the U.S. economy and enables national defense, even as it deals with historically low global shares and reduced domestic employment.

Domestic Diffusion and Adoption of Advanced Manufacturing

Not surprisingly, every manufacturer Team AdMan visited claimed they applied advanced manufacturing techniques. Yet, each offered a different explanation for why its manufacturing was advanced. This observation correlates with the broad nature of PCAST's definition and the ever-expanding advanced manufacturing toolkit, while providing insight into the challenges associated with studying advanced manufacturing.

This section focuses on the diffusion and adoption of additive manufacturing or 3D printing, perhaps the most familiar advanced manufacturing technique. Additive manufacturing is neither new nor particularly revolutionary. Although the basic technique dates back to 1951,[21] it wasn't until 1984 that Charles W. Hull patented the additive manufacturing process, later coining the phrase "stereolithography" to describe the layering process.[22] Today, the American Society for Testing and Materials (ASTM) identifies seven categories of additive manufacturing. Table 1 in Appendix A lists and briefly describes each method. Of the seven methods, binder jetting, sheet lamination,[23] powder bed fusion, and directed energy deposition support metal-based additive manufacturing.[24] The aerospace industry and other DoD applications most frequently employ fused deposition modeling (FDM), a material extrusion process, and direct metal laser sintering (DMLS), a powder bed fusion process.[25]

Obtaining statistics specific to advanced or additive manufacturing revenues or employment, similar to those available for manufacturing as a whole, proved difficult. Wohlers Associates estimated that additive manufacturing revenues and services worldwide grew from $642.6 million in 2011 to $1.065 billion in 2013 to $5.165 billion in 2015.[26] Team AdMan identified three main factors behind this accelerating growth in revenue: expiring equipment patents, increasing access to materials, and advancing technology.

First, expiring patents on the 3D printing process spurred much of the recent excitement associated with the relatively old additive manufacturing process. As a result, more companies are building 3D printing equipment.[27] Wohlers Associates reported the number of companies selling industrial-grade additive manufacturing systems rose from 31 in 2011 to 49 in 2014 to 62 in 2015.[28] Despite this growth, four companies currently dominate the industrial 3D printing equipment market—3D Systems, Stratasys, EOS, and Arcam, accounting for 31% of the market.[29]

U.S. companies possess an advantage in photopolymer and thermoplastic 3D printers, while European companies enjoy market leadership for metal powder 3D printers.[30]

Second, increasing access to 3D printing base materials is expanding additive manufacturing's applications. Once limited to photosensitive resins and plastic filaments, the availability of raw materials is now expanding to metal powders and composites.[31] Traditionally, DoD has limited the use of 3D printed parts to non-structural parts (e.g., UAV components, ducts, motor brackets, seat belt buckles).[32] However, continued advances in metal powders and composites are bringing DoD closer to the use of 3D printed parts for structural components.[33]

Finally, advances in technology are enhancing 3D printing processes and feasibility. The 3D printing equipment is now more capable, reliable, and controllable. At the same time, other innovations such as the use and coordination of information, robotics, computation, software, sensing, and networking are creating new opportunities for 3D printing. When combined, these still expanding developments constitute a manufacturing revolution. Appendices A and B provide additional information on additive manufacturing equipment vendors, technologies, base materials, and advantages and disadvantages.

U.S. Efforts to Advance Innovation and Manufacturing

The Obama Administration and Congress have promoted innovation and advanced manufacturing.[34] In 2009, President Obama "formalized his science and technology advisors" as the PCAST;[35] they have since published four reports on advanced manufacturing.[36] Collectively, these reports emphasize that "manufacturing contributes disproportionately to U.S. innovation"[37] and offer 16 recommendations to further advanced manufacturing under the pillars of enabling innovation, securing the talent pipeline, and improving the business climate.[38]

The Administration implemented a number of the recommendations. The most tangible policy established the NNMI, operated by the Advanced Manufacturing National Program Office (AMNPO).[39] In his fiscal year 2014 budget, President Obama asked Congress to authorize a one-time infusion of $1 billion to establish and support up to 15 manufacturing innovation institutes on a cost-shared basis with private and non-federal funds to "scale up advanced manufacturing technologies and processes." The President proposed that 45 institutes be established over 10 years.[40]

The Obama Administration has already allocated over $500 million in support for the NNMI.[41] Currently, nine institutes have stood up or been announced. The first NNMI Manufacturing Innovation Institute, AmericaMakes, stood up in 2012, receiving $30 million in federal funding matched by $40 million in cost-sharing.[42] The most recent in April 2016, Advanced Functional Fabrics of America (AFFOA), will receive $75 million in federal funding matched by $242 million in cost-sharing.[43] In addition, the AMNPO released a Federal Funding Opportunity to fund one or more NNMI institute(s) via an open competition that will be decided in the first quarter of 2017 and provide up to $70 million of federal money over five years.[44] Table 2 in Appendix A provides basic information on each NNMI institute. See Essay #4 for more on Innovation Centers.

Team AdMan visited America Makes, Digital Manufacturing and Design Innovation Institute (DMDII), and PowerAmerica during its field studies. During these visits, the team was exposed to projects leveraging the Triple Helix of government, industry, and academia working together to foster innovative solutions to known challenges and create beneficial regional environments.[45] The enthusiasm and support at the local and regional levels proved refreshing, and even inspiring. The institutes were generating meaningful collaboration across a variety of technology transfer opportunities. However, Team AdMan received little on quantitative measures of effectiveness, beyond level of matching funds and number of members.

The DoD has implemented steps to further spur defense-related innovation. First, in November 2014 the Secretary of Defense announced an initiative to "develop new military technologies and operational concepts," termed the third offset strategy.[46] Targeted technologies included directed energy weapons, human performance modification, automated unmanned systems, miniaturization and nanotechnology, hypersonics, advanced manufacturing, robotics, and advanced computing and big data.[47] Second, DoD introduced the Defense Innovation Unit – Experimental (DIUx) "to create a hub for increased communication and collaboration with, knowledge of, and access to innovating, high-tech companies and executives and their leading edge technologies."[48] The DoD stood up the first DIUx in Silicon Valley in August 2015 and announced the second DIUx in Boston in May 2016. [49] Finally, the DoD maintains existing programs focused on manufacturing, specifically the Manufacturing Technology (ManTech) Program to anticipate and close "gaps in manufacturing capabilities for affordable, timely, and low-risk development, production, and sustainment of defense systems."[50]

Foreign Competition and Their Innovation Models

Although Chinese manufacturing tends to draw the most attention, Germany and Japan retain highly capable manufacturing sectors that effectively incorporate advanced manufacturing techniques, tools, and processes.[51] In addition, PCAST's reports concluded that the U.S. is lagging behind other nations (e.g., Germany and Japan) in the skilled work force required to compete in a global manufacturing environment.[52] But, instead of focusing on the German and Japanese manufacturing sectors, the AdMan Team examined each country's innovation system in search of lessons that could benefit the U.S. advance manufacturing transformation.

Germany

In 2010, "manufacturing in Germany employed 22% of the workforce and contributed 21% of GDP."[53] A 2014 Harvard Business Review (HBR) essay identified three factors behind Germany's continued industrial base strength. First, German innovation brings new ideas and technologies to existing industries as well as seeks to form new industries. Second, the Fraunhofer Institutes, with government support, aid technology transfer across the entire industrial sector. Third, Germany constantly trains its work force, empowering workers and improving their productivity.[54] HBR states the purpose of innovation in Germany is "to sustain productivity and employment growth in order to ensure real income expansion," something the U.S. does not fully embrace.[55] Observations during Team AdMan field studies support this claim.

The PCAST raised the Fraunhofer Institutes as a possible model for the NNMI.[56] Founded in 1949, the Fraunhofer-Gesellschaft (Fraunhofer Society) focused on various fields of applied science. Early on, the government instituted the society within the country's non-university research enterprise. The first Fraunhofer Institute opened in 1954 and quickly partnered with the Ministry of Defense. By 1959, the society included 9 institutes and employed 135 individuals with a federal budget of $860,000[57] (approximately $7 million in 2015 dollars[58]). By 1969, the society had grown to 19 institutes, over 1,200 employees, and an $8.4 million[59] budget (nearly $55 million in 2015 dollars[60]). Currently, the society includes nearly 60 institutes with a total workforce of 15,000 and the budget exceeds 1.4 billion Euro ($1.58 billion),[61] including seven institutes inside the U.S. under Fraunhofer USA.[62]

The Fraunhofer financing model expects institutes to earn about 70% of income through industry and government contracts and 30% through federal and state grants.[63] Thus, the size of an institute's budget is directly tied to its own commercial success and the revenue it generates. Team AdMan considers the Fraunhofer model extremely successful for generating economic growth. Lessons for the U.S. include the value of public-private partnerships to advance technology transition and the need to provide time for the institutes to grow.

Japan

In 2012, Japan's manufacturing industry employed 17% of the workforce and contributed 19% of GDP."[64] Like the U.S., Japan is struggling to maintain consistent, solid economic growth. Its three main challenges are a decreasing population that is simultaneously aging, a national debt that exceeds 200% of GDP, and structural issues that stifle innovation. Japan's insular society exacerbates all three challenges. Recognizing these challenges, the Japanese Government, pursued a three-pronged program consisting of an aggressive fiscal policy, an aggressive monetary policy, and structural reform. Team AdMan focused on the developing structural changes aimed at enabling innovation and technology to drive economic growth.

To enhance innovation, Japan strengthened the Council for Science, Technology, and Innovation (CSTI) and created the Acquisition, Technology and Logistics Agency (ATLA) under the Ministry of Defense (MoD). Beginning in 2013, the CSTI initiated three new efforts: 1) it pursued strategic formulation of the overall government science and technology budget and took the lead in directing prioritized allocations of that budget; 2) it created the Cross-ministerial Strategic Innovation Promotion Program (SIP); and 3) it initiated the Impulsing Paradigm Change Through Disruptive Technologies (ImPACT) effort. As a result, the CSTI allocated 50 billion yen ($460 million[65]) for SIP in 2015 and 55 billion yen ($506 million[66]) for ImPACT in 2013.[67] In addition, the CSTI selected 10 cross-ministerial SIP projects in 2014 that "answer critical social needs and offer competitive advantage to Japanese industry and the economy" focused on energy, next-generation infrastructures, and local resources.[68] The CSTI selected directors for each issue program from among "top-class leaders in industry and academy."[69]

While Japan chartered the CSTI to drive cross-ministerial science and technology efforts, it stood up ATLA in October 2015 to provide defense acquisition program management throughout the program lifecycle.[70] To spur innovation, the MoD assigned ATLA control of security-related technology research funding intended to discover basic research by universities, public sector research institutes, and private companies aligned with identified research areas and themes. Selected projects receive up to 30 million yen ($275,000[71]) annually for a period of one to three years. The government appropriated 600 million yen ($5.5 million[72]) for this program in fiscal year 2016.[73] ATLA does not yet coordinate research topics, themes, or efforts with CSTI.[74]

Like the NNMI, Japan's structural changes are new and difficult to assess. One challenge SIP and, particularly, ATLA face is Japanese academia's refusal to support defense-related research efforts.[75] Lessons for the U.S. include the need for defense-related and national-level research to coordinate to avoid unnecessary duplication of effort and the need to seek opportunities of shared research efforts between the U.S. and global allies.

Outlook

Advanced Manufacturing

As previously mentioned, the adoption of advanced manufacturing techniques, tools, and processes is driving a significant and potentially revolutionary transition in U.S. manufacturing. This on-going revolution, however, is far from complete. Advanced manufacturing has penetrated most sectors of industry and will continue to diffuse throughout the economy.[76] The general consensus projects advanced manufacturing, primarily additive manufacturing, will reach mainstream adoption in five to ten years, both within industry and the DoD. Companies visited during Team AdMan field studies indicated that they expected to start seeing meaningful returns on their investment in advanced manufacturing efforts between three to ten years out.[77] In 2012, Wohlster Associates projected revenues associated with additive manufacturing revenues and services to exceed $6.5 billion by 2019.[78] McKinsey Global Institute analysis project that applications of 3D printing could have "direct economic impact of $230 billing to $550 billion annually in 2025.[79]

In addition to greater and more productive use of advanced and additive manufacturing techniques, ongoing research, development and technology transfer efforts will enhance the capabilities of additive manufacturing and improve processes and approaches. Manufacturers will be able to vary the microstructure within and properties of parts, choose from a wide variety of materials, and eliminate porosity[80] in manufactured parts. Users will be able to employ and exploit sophisticated process monitoring and controls to enhance product quality and process consistency. The equipment will be more capable and open platform software controlling operations will become more common.

In large portions of the manufacturing industry, the manufacturing of tomorrow will look much different than the manufacturing of yesterday or, even, today (see Essay #1 for further discussion on the "brilliant" factory of the future). Fixed structures swarming with laborers, fabricators, and mechanics will be replaced by mobile equipment leveraging man-machine interactions and mechanics, roboticists, designers, engineers, and software programmers. All of this could contribute to a somewhat resurgent U.S. manufacturing sector. However, the result will be a different version of manufacturing than of years past. Machine-to-machine (M2M) interfaces, digital manufacturing driven by artificial intelligence, and interconnectedness via the Internet of Things (IOT) will all be commonplace in the factory of the future.[81] Termed the 4th Industrial Revolution, this fusing of previous technologies will transform the advanced manufacturing sector by "integrating breakthroughs in artificial intelligence, nanotechnology, biotechnology, materials science, big data, the IOT, robotics, and quantum computing."[82] The resulting automation of processes will allow for mass customization, efficiency, effectiveness, and a reduced waste stream.[83]

Cross-disciplinary teams and work centers will become the norm as previously separate steps within the manufacturing process merge. For example, a theme repeatedly raised during the Team's research and field studies is the increasingly inherent need for the product design to involve the design of the manufacturing process to produce the product. The changing work environment will drive a change in how future workers are educated at all levels. Universities will need to change curricula so that they prepare students for the manufacturing floors of the future. These changes must occur relatively quickly because retiring Baby Boomers, coupled with continued economic expansion, are projected to create an environment where manufacturing jobs far exceed the availability of appropriately skilled workers. Analysts project that the number of unfilled manufacturing jobs due to the skills gap will rise to 2,000,000 by 2025.[84] This presents a wonderful opportunity for the Digital Natives, provided they, their parents, and their educational institutes recognize the opportunities available. The medical field offers other opportunities – see Essay #3 for discussion of advanced manufacturing in medicine.

Within the DoD, additive manufacturing has the potential to transform the military supply chain radically. Instead of stocking vast warehouses in a few centralized locations and shipping spare parts on an as needed basis around the globe, the U.S. military could preposition 3D printing equipment and technicians in forward locations to build necessary parts on location. For example, the U.S. Navy could pre-position an additive manufacturing capability in Bahrain to support platforms operating in the Middle East (see Essay #2 for a view of industrial mobilization in an era of advanced manufacturing).

U.S. Government Policy

Industry moves forward when and where they find a return on investment. Government, at the local, state, and national level, all can affect how quickly, or even whether, industry sees a return on investment. Specifically, at the federal level, Team AdMan found it difficult to determine the outlook. A plethora of questions on future government policy are unanswerable at this point in time. An important issue is whether the president elected in November 2016 will continue to emphasize advanced manufacturing, the NNMI, and the Third Offset Strategy pursued during the Obama administration. Will the complexity of the issues and challenges faced by manufacturers in highly competitive environments be understood and addressed with nuance and wisdom or will other approaches be taken? What will be the political environment in Washington, D.C.? Will Congress and the administration work together or trade obstructionist blows? Will the nation seek collaborative win-win solutions to the global economic challenges or seek isolationist and purely inward looking paths? Perhaps the most important question addresses whether or not the existing challenges, detailed in the next section, will be seen as roadblocks or opportunities.

Opportunities to Further Advanced Manufacturing

The concepts discussed in the outlook are likely to occur; however, achieving them will require dedicated political and intellectual effort. Removing hurdles could accelerate the adoption of the more promising advanced manufacturing applications. Team AdMan aligned the opportunities it identified under three main challenges—innovation impediments, skills shortfalls, and business barriers. This grouping mirrors PCAST's three pillars of enabling innovation, securing the talent pipeline, and improving the business environment. Essay #9 provides a look at how advanced manufacturing can benefit U.S. national security.

Innovation Impediments

Government, industry, and academia should work together to create an environment conducive to innovation, technology transfer, and building a talented advanced manufacturing workforce.[85] Collaboration occurs readily when everyone gets something from the relationship; it tends to break down when information is not shared. In business, and even academia, information is power and may provide a competitive advantage. Defining expectations regarding what to share and what to protect as intellectual property will help keep these relationships working as intended. As the complexity of the equipment, raw materials, and processes continue to increase, so too will the complexity of intellectual property protection and controls, both within the collaborative groups and external to the groups.

Dynamics associated with the availability and limitations of equipment present a second innovation impediment. The largest U.S. companies, Stratasys and 3D Systems, primarily sell 3D printers that use photopolymers and thermoplastics. The largest German companies, EOS, SLM Solutions, and Concept Laser, account for 80% of all metal additive manufacturing systems sold.[86] This distinction is important because "the metal branch of additive manufacturing is growing more rapidly than the rest of the industry. In 2014, the unit sales of metal additive manufacturing systems increased more than 50%, considerably above the overall industry."[87] Additionally, the cost and capacity of systems is a significant barrier. High-end, commercial grade printers can cost between $250,000 and $1 million, yet the largest parts they can produce are still much smaller than those from traditional manufacturing processes.[88] Other equipment challenges include: the amount of time needed to produce parts; the lack of standard in situ process monitoring sensors; and effects of build orientation on part structure and tensile forces.[89]

Software that operates the additive manufacturing systems is, in all known cases, a closed loop system.[90] Large companies have set the precedent of writing their own or modifying existing operating software, but capital invest required to do this is beyond the capability of smaller organizations. This is also risky, because software controls may limit what a manufacturer can do with the equipment unless they are willing to invalidate the warranty and/or support agreement.

Raw material consists of metal powder (commonly steel, aluminum, nickel, cobalt-chrome, copper, and titanium) which is created by gas or water atomization. The powder is not sold in large enough quantities to attract large providers. It is generally sold by additive manufacturing system providers and can cost 200 times more than sheet metal.[91] While traditional manufacturing is able to use a wide variety of materials such as metals, alloys, and composites; additive manufacturing remains constrained by the availability of equivalent material options.[92] Adding to this challenge, the material and structural properties of even well-known and traditional materials differ for additively manufactured products. The relationship of material and powder properties to part properties is not well understood.[93] However, research continues to expand the portfolio of available materials and achieve greater strength, conductivity, and hardness.[94]

Skills Shortfalls

Eighty-four percent of advanced manufacturing executives believe there is a "talent shortage in the U.S. manufacturing sector."[95] The lack of skilled workers results in a failure to maintain or increase production to meet customer demand, an inability to implement new technologies, and a difficulty in developing new products—all contribute to lost revenue.[96] By 2025, with 2.7 million Baby Boomers retiring, an additional 700,000 openings anticipated from economic expansion, and only 1.4 million positions expected to be filled, an estimated 2 million American manufacturing jobs may go unfilled unless more people choose a career in manufacturing.[97] Unfortunately, a large contributor to the current and future skills gap is the outdated perception of advanced manufacturing as a dark, dirty, and dangerous occupation and belief that manufacturing jobs are among the first to be off-shored.[98] While a vast majority of Americans believe that manufacturing is important to U.S. economic prosperity and national security, only 37% would encourage their children to pursue a career in the industry[99] and, in surveys, Millennials ranked manufacturing as their least desired career choice.[100]

In addition, the U.S. lacks a comprehensive, stackable set of skills certifications across the advanced manufacturing industry to enable a standardized path for talent-growth. This makes coordination between industry and academia difficult. Also, the lack of a common certification system marginalizes workers who are either displaced or seeking new employment options.

A commonly identified challenge lies in finding the right and/or properly qualified employees to manage and operate advanced manufacturing efforts. Education institutions, in general, and at every level (secondary, community college, and university) have failed to adjust curricula to account for the technology focus of advanced manufacturing along with the cross-disciplinary skillset needed for advanced manufacturing.[101]

Additive manufacturing requires greater computer skills than other manufacturing sectors. Both additive manufacturing and the advent of the industrial IOT[102] will increasingly rely on data analytics, modeling and simulation, and an understanding of data architecture. Based on a 2015 Deloitte skills gap report, 70% of surveyed employers felt the technology/computer skills of their existing workforce were insufficient.[103] This is before additive manufacturing and industrial IOT gain wide adoption in the industry. Future competency models must consider which education tier should include these skills. This finding suggests existing manufacturing competency models (and academic curricula) may be inadequate in preparing workers for the increased data and computer usage required by disruptive innovations in manufacturing.[104] Skills like data analysis and computer utilization should be added to existing manufacturing competency models to ensure workers are prepared for the increasing technology associated with advanced manufacturing.

Business Barriers

Team AdMan identified four key barriers that advanced manufacturing presents to firms. First, advanced manufacturing techniques, tools, and processes require capital intensive investments. Additive and other advanced manufacturing equipment can be expensive to purchase and maintain. In addition, return on investment may take longer than for traditional manufacturing equipment. This occurs because these processes are not yet well understood and historical information and adequate training are not as prevalent. Thus, moving from traditional to advanced manufacturing often requires significant research and development. This combined capital and knowledge burden is a barrier to entry for many firms.[105]

Second, few standards exist that specifically address additive manufacturing. From materials to machinery, there is no universal qualification and certification for many advanced practices. This lack of standards affects manufacturers' ability to ensure repeatable part quality and accuracy, especially when compared to parts produced using the well-established traditional manufacturing processes. The absence of standardization also negatively impacts the confidence of the end-user and stifles the willingness of some companies to embrace advanced manufacturing.[106]

Third, advanced manufacturing practices tend to be data-intensive. As a result, the data files required for advanced manufacturing are large and difficult to share across limited-bandwidth networks.[107] The US was ranked 17th globally in 2015 for "average peak internet speed."[108] This means that the U.S. may not have the bandwidth to handle the expected traffic.

Finally, the U.S. corporate tax structure is a burden on U.S. companies. With a combined corporate income tax rate of 39 percent, the U.S. has the highest corporate income tax of any Organization for Economic Cooperation and Development (OECD) nation.[109] Much can be done in that realm to provide incentives and tax relief for U.S. businesses. There are many additional challenges to improving the business environment but Team AdMan elected to focus on the most prominent and recurring impediments observed during its field studies.

Recommendations

The U.S. government and the DoD have a vested interest in ensuring the U.S. manufacturing industry embraces advanced manufacturing techniques and processes. In *America Inc.?: Innovation and Enterprise in the National Security State*, Linda Weiss argues the American state "has played a catalytic role in nurturing technological innovation and founding new industry sectors."[110] She also observes that historically the nature of that support "derives not merely from the entrepreneurship of its private sector...but from the national security state—a particular cluster of federal agencies that collaborate closely with private actors in pursuit of security-related objectives."[111] In light of this, several of the Team AdMan recommendations are intended to foster innovation. They fit under the three PCAST pillars used throughout this paper, and consist of a mix of government-wide and DoD-specific proposed actions.

Enable Innovation

Advance Policies that Structurally Promote Interaction between Government, Industry, and Academia (the Triple Helix). The government should advance policies that promote interaction between the government at all levels (federal, state, and local); industry, including companies of all sizes (particularly small and medium enterprises); and education institutes from the primary level through research institutions. The Administration should continue to allocate resources in support of NNMIs, ensuring awards go only to bidders with a strong and balanced public-private-academic team.[112] The dollars devoted to these ventures foster relationships required to advance America's industrial base. The new Defense Innovation Unit-Experimental in California is an encouraging start.[113] Challenging DoD's culture to embrace a diverse view of innovation will help maintain America's technical edge. Further expanding these initiatives are a prudent means of enabling further innovation. The desired structural change, however, requires patience; these policies must be given adequate time to yield returns as demonstrated by the Fraunhofer example.

Establish a designated program office and create a DoD program of record to foster service level introduction of additive manufacturing. The DoD should create a Program of Record (POR) and Program Office in support of advanced manufacturing. This paper includes themes advocating that the government should continue to grow its stimulus of the advanced manufacturing sector. Although the DoD has taken steps in this direction at various command levels, the commitment falls short of the necessary measures required in leveraging this capability across a service or more optimally throughout DoD. The Department and service components have a myriad of efforts to further advanced manufacturing, but they lack coordination and standardization. By creating a Program of Record (POR) and a Program Office, the DoD would be better positioned to manage and consolidate ongoing efforts toward a common goal. Such a POR would also stabilize advanced manufacturing funding, and centralize oversight authority to minimize instability during periods of leadership transition and fiscal volatility. Essay #5 is a representative example of how a military service component could incorporate and leverage advanced manufacturing.

Secure the Talent Pipeline

Debunk Poor Perceptions Regarding U.S. Manufacturing Careers. The Department of Commerce should conduct a national campaign, in conjunction with a grass roots initiative, to encourage careers in manufacturing. The national program would establish a framework, create templates for tailoring to the local requirements, and provide resources and funding for communities. Changing perceptions about manufacturing is a personal endeavor which is why the local outreach, under the national umbrella, is so important. Each community understands the manufacturing needs for technicians, mechanics, designers, engineers, and researchers and can show the tangible and projected benefits of the industry. This is already being done to some degree with programs such as National Manufacturing Day, but they are disjointed and implemented in pockets. To be successful, stronger national focus should be continued by the states and holistically implemented in every manufacturing or potential manufacturing community in the U.S. On a related note, Essay #7 looks at Right To Work and its impact on advanced manufacturing.

Enable Comprehensive, Stackable Sets of Skills Certifications. The Department of Labor's Employment and Training Administration (ETA) and the National Association of Manufacturers (NAM) should standardize manufacturing competency models to ensure foundational skills are common across all manufacturing sectors. The manufacturing industry has developed specific competency models to better match workers to employees. The industry has elected to subdivide manufacturing into four separate competency models: advanced manufacturing, automation, aerospace, and mechatronics. However, the common or foundational skills required for the four competency models are not standardized. The individual skills required inside common competencies vary across the manufacturing industry. Unfortunately, the lack of commonality between these four competency models sends a confusing signal to educators and future workers. Essay #6 discusses issues surrounding this specifically in the DoD.

Better Foster Growth of Strong, Open-Minded DoD Leaders. The government should also promote strong, open-minded DoD leaders who can implement innovative change within the government bureaucracy (see Essay #8 for a relevant example). One way the services can do this is by increasing fellowship opportunities within industry and advanced degrees at civilian institutions. NNMI institutes would be a great industry location for upwardly mobile junior officers. These experiences develop an officer's strategic perspective and promote diversity of thought. Perhaps more importantly, these opportunities will expand an officer's personal network and increase his or her credibility in diverse communities. These relationships are often the most important element of spurring innovative thought to advance our defense industrial base.

Improve the Business Environment

Build up the cyber infrastructure and protections that will enable and protect the advanced manufacturing networking requirements. The Federal Government, in conjunction with industry, should build the cyber infrastructure and safeguards that will enable and protect networking requirements. During field studies, Team AdMan learned of a variety of techniques used to transport and protect the large data files, often containing intellectual property and or restricted technology information, associated with advanced manufacturing. These techniques ranged from standalone networks to physical movement of the information to and from the equipment using data storage media to protect from outside infiltration. While currently effective for the limited applications of advanced manufacturing today, these techniques will not support the timely transmission of advanced manufacturing data files between geographically separated entities of the manufacturing process in the more widespread applications of the future.

Redouble efforts to establish standards and research into process controls and repeatability. A lack of standards exists for additive manufacturing equipment and product qualification and certification.[114] Additionally, mechanical properties of printed parts vary based on the additive manufacturing process employed; including equipment parameters, material properties, and post fabrication and treatment processes.[115] The additive manufacturing technology used also affects the final structural characteristics and properties of the product. These create challenges for the additive manufacturing industry in consistent reproduction of parts of equal quality. To overcome these challenges, robust and defined certification standards, approaches and processes should be developed for additive manufacturing technologies. Collaboration between the National Institute of Standards and Technology (NIST) and representatives of the additive manufacturing industry is instrumental in developing these standards, approaches and processes. Establishing standards for equipment that lead to certified parts for use in tightly controlled industries will streamline production and lower overall costs.

Reform Corporate Tax Law. Corporate tax reform would go a long way to keep innovative firms rooted in the U.S. as they grow from small to medium, and larger. Congress should consider lowering tax rates for manufacturing companies, eliminating taxes on revenue gains overseas, and expanding research and development credit while increasing tax deductions for using additive manufacturing practices.[116] Corporations must have the proper incentives to ensure their operations remain on U.S. soil and can compete effectively. Additionally, incentives to hire U.S. workers and maintain operations in the U.S. must be captured in the U.S. tax code.

Make it Easier for U.S. Businesses to Work with DoD. Bloomberg Government reported in 2012 that the DoD had missed its target of awarding 22.3% of contracts to small businesses in 2011, and had missed similar targets each year for the nine preceding years.[117] Throughout our travels, small and medium enterprises (SME) consistently indicated that working with the U.S. Government was too complicated to make it worth the effort. Despite DoD senior leadership's clear desire to increase the share of SMEs working with the Pentagon, watchdog groups are unimpressed. Last year, several groups joined to challenge the small business contracting data the DoD released in June 2015.[118] In it, the Small Business Administration counted several Fortune 500 companies in the list of small businesses that helped the U.S. Government reach 105.46% of its goal.[119] Team AdMan did not research this claim. Nevertheless, the feeling clearly exists that if a SME wants to work with the U.S. Government, it is easier to take on a sub-contractor role to a larger company who wins the prime contract with the government.

Conclusion

Advanced manufacturing and everything it offers has a foothold in the U.S. manufacturing industry. Mass implementation is likely within the next 5-10 years. However, it will take time to achieve all potential benefits associated with advanced manufacturing. Before all Rosie the Riveters can set down their rivet guns, a number of technological challenges still exist, as do structural barriers and outdated practices and mindsets.

In the long term, enabling innovation via the Triple Helix through programs such as NNMI or from more grass-roots initiatives at the DoD service component level will ensure that the U.S. maintains its technical edge far into the future. In the medium range of 5-10 years, we must prepare the Digital Natives for their future by securing the talent pool through messaging about manufacturing opportunities, standardized certifications, and, in the DoD, ensuring their supervisors are ready to make use of them. In the short-term, the business environment has to be friendly to manufacturing. This can be done by providing businesses the cyber infrastructure and updated manufacturing standards they need. Also, reducing the cost of doing business in the U.S. by reduced taxes will help across the board and competition will improve by making it easier to do business with the DoD.

Team AdMan had the privilege of visiting a variety of government, industry, and academic organizations driving and/or adapting to the advanced manufacturing revolution. The Team saw companies big and small, on the leading edge and not, and heavily invested in advanced manufacturing and not. U.S. Industry is excited about advanced manufacturing's potential, but won't get there on its own. This will only occur if the U.S. collaboratively continues to enable innovation, secure the talent pipeline, and improve the business climate. The required changes will not occur overnight; but require strategic patience combined with an appropriate sense of urgency and policy consistency to get the U.S. where it needs to be. When broken down to the basics, it really is just a story of ensuring that Rosie the Riveter becomes the Digital Native she was destined to become.

ESSAYS ON MAJOR ISSUES

Essay #1
Brilliant Factories: Advanced Manufacturing's Nirvana

Today, the combination of technologies such as big data, advanced analytics, hyper connectivity, and sensors are driving the manufacturing industry to greater heights. The extraordinary changes taking place within manufacturing are creating what some experts are labeling the next industrial revolution, following Henry Ford's assembly line and Toyota's lean manufacturing.[120] According to General Electric (GE), the promise of these technologies is being realized in its "brilliant factory," and if successful, GE's vision will have significant and positive implications for the Department of Defense.

The revolutionary aspect of the brilliant factory is not in how it makes things, but rather how it analyzes the entire lifecycle of the things it makes. As Katie Moore, an industry marketing manager at GE, described the brilliant factory: "it's about employing a digital thread – seamlessly tying the flow of information from design through manufacturing to end consumers, including the full life-cycle of the product."[121] The brilliant factory focuses on connecting every aspect of the digital thread, and creating "manufacturing's 21st Century Assembly Line."[122] This modernized assembly line is the combination of sensors, big data, advanced manufacturing, and supply chains.

The brilliant factory will trace all aspects of the lifecycle chain by connecting smart machines and analyzing the digital thread of products to achieve new levels of productivity and efficiency.[123] This is made possible by combining sensors, data storage and advanced analytics. Engineers, designers, and suppliers can place sensors on various machines, mine huge amounts of data, store that data, and analyze it with powerful, advanced software.[124] Ultimately, the brilliant factory aims to combine traditional industries, or "Big Iron," with vast amounts of data and powerful analytics, or "Big Data," in order to achieve previously unattainable efficiencies.[125] In connecting and analyzing the digital thread (the data from design to production to distribution to operation) throughout the lifecycle of products, the brilliant factory also delivers a priceless capability to digitized businesses—speed. This increase in speed will increase the pace of innovation, feedback, and process improvement, transforming manufacturing.[126]

But, a potentially even more promising aspect of brilliant factories is what Carnegie Mellon engineers have labeled "mass manufacturing in quantities of one."[127] When constructing large structures, much of the manufacturing cost arises from designing and constructing the assembly plant. The price and massive size of such plants limit the "flexibility and scalability of the manufacturing process."[128] The costs also make it necessary to build large quantities of the product, otherwise economies of scale make the endeavor untenable. However, brilliant factories have the potential to enable "mass production in quantities of one" and ignite a revolution in how large-scale products are manufactured.[129]

"Agile factories" will enable one-off, large structures to be built in a cost-effective way and will be able to rapidly respond to market demands and shifts. Enabling this "do everything" factory are data-sharing robots and data-sharing factory floors as well as flexible robots that are built to perform multiple functions. Researchers at Carnegie Mellon are examining new methods for manufacturing, to replace the current and costly stationary fixtures and space associated with modern factories. This approach requires complex connectivity amongst the supply chain, systems, and designers to choreograph the robots, parts, and tools. In essence, Carnegie Mellon's mobile manufacturing concept takes the technology of the brilliant factory, and re-imagines this capability in a factory of the future. The result is immensely promising. As the Carnegie Mellon Team noted, "of particular interest is the assembly of large structures where in current practice, customized facilities incorporating extensive infrastructure in the form of fixed tooling, permanent fixtures, and special systems are built to enable efficient, high precision manufacturing of a specific product.[130] The ability to replace extremely-expensive production facilities with small, mobile, and agile automated production factories would truly transform the manufacturing industry. For DoD, the positive implications of the brilliant and agile factory concepts include reduced operational downtime, more efficient "just-in-time" supply chains, and large weapons of war that can be economically purchased in small quantities.

Essay #2
Industrial Mobilization in an Advanced Manufacturing Era

The concepts of industrial mobilization continue to evolve and advanced manufacturing practices will have some impact on way the military and nation mobilize for conflict in the future. It took 44 to 70 months to mobilize the U.S. during World War II, and the U.S. will not have the luxury of that much time in the future. The concept of mobilization now, and in the future, will be on a smaller and more agile scale because it will be a matter of months before the tipping point to failed deterrence will determine whether nuclear warfare is a likely course of action.[131]

Advanced manufacturing practices provide high-technology solutions to future defense challenges allowing the U.S. to re-characterize how the concept of mobilization is employed. Additionally, the expeditionary model of additive manufacturing changes the way one should think about industrial mobilization. It is not out of the realm of possibility to think that this application, given proper development, might shorten the supply chain and provide flexible options for our warfighters in the near future. That said, there are limits to nearly every aspect of military doctrine, organization, training, material, leadership, personnel, and facilities (DOTMLPF) that currently prevent widespread implementation of additive manufacturing practices in the expeditionary environment and as a mobilization multiplier.

In order to reduce those limits, governments at all levels can focus on policy that creates an environment conducive to innovation while providing investment such that it allows industries using advanced manufacturing practices to overcome market failures. Corporate tax reform would go a long way to keep innovative firms rooted in the U.S. as they grow from small, medium, to potentially larger in scale and scope. Additionally, a corporate tax holiday would give incentive for firms to onshore their headquarters, further boosting the U.S. defense industrial base. Finally, the U.S. Government should continue or better yet, expand what is already being implemented in the form of public-private institutes supported by federal research and development funds.

Essay #3
Advanced Manufacturing in Medicine

The United States is a world leader in most of the fields around medicine, including medical device manufacturing, advanced drug manufacturing, and cutting edge procedures in medicine. One way that the country can maintain that lead is by leveraging advanced manufacturing techniques. Areas in which advanced manufacturing is being used in medicine include 3D printing and technologically advanced drug manufacturing. 3D printing is being used traditionally to print inorganic items for use in medicine and to print organic materials.

Inorganic additive manufacturing is already used to 'print' replacement joints, bones, or teeth. Doctors have used 3D printing to produce knees[132], hip joints[133], and even entire pelvises[134], as well as false teeth with antimicrobial properties.[135] 3D printing makes prosthetics more comfortable, useful, and inexpensive. Modern sensors and scanners significantly improve the fit of a prosthetic, computer aided design maximizes functionality, and open access intellectual property for prosthetics has drastically reduced the cost. The use of MRI and CT scanners to produce models of the conditions found in a patient's body allowed surgeons to plan and rehearse a very complicated separation of conjoined twins in early 2015.[136]

The use of 3D printing for organic materials, or bioprinting, holds great promise. Clinicians hope to someday be able to print new organs for patients, but it has been limited thus far to skin and cartilage substitutes, heart valves (containing two types of cells)[137], and liver cells for drug testing purposes.[138] Some of the most valuable work done in bioprinting has been the printing of cellulose for burn victims, which shows great promise in natural skin regrowth.[139] There is much work to be done, but it is only a matter of time before printing organs is a reality.

The Defense Advanced Research Projects Agency (DARPA) has used their Pharmacy on Demand and Biologically-derived Medicines on Demand programs to demonstrate that the use of advanced sensors and modern computing power can substantially improve drug manufacturing processes. Current drug-making processes are largely 50-year-old techniques, which are wasteful and inefficient. Quality is difficult to manage during the process. The two on Demand programs improve significantly on all these fronts, because the processes reduce production time, use smaller amounts of ingredients, and less energy. Also, because of the sensors, these programs monitor quality much better.[140]

Essay #4
Innovation Centers

On February 9, 2016, the National Institute of Standards and Technology's Advanced Manufacturing Office released a Federal Funding Opportunity to fund one or more National Network for Manufacturing Innovation (NNMI) Institutes. The winner of an open competition, that will be decided upon in the first quarter of 2017, will have access to $70 million of federal money over five years.[141] According to the competition, the institute can focus on any area of advanced manufacturing that is not duplicated by another of federally funded NNMI institute. Table 2 in Appendix A of this report lists the current existing or planned institutes. The following advanced manufacturing disciplines remain unaddressed: *Nanomanufacturing*; *Biomanufacturing and Bioinformatics*; *Industrial Robotics*[142]*;* and *Advanced Ceramics.*[143]

The Revitalize American Manufacturing and Innovation Act of 2014 gave birth to the NMMI to establish a program similar to the Fraunhofer Institutes. The NNMI institutes would be given federal financial assistance (which must be matched by state and private funds) for seven years with the amount to decrease after the second year and each year thereafter unless the institutes were meeting stated goals and metrics. The program would incorporate the existing Hollings Manufacturing Extension Partnership and Regional Innovation Strategies Program to ensure the participation of small and medium-sized entities (SMEs).[144]

According to the PCAST 2015 annual report, the seven existing institutes now include over 820 members (universities, SMEs, and state and federal agencies). The $520 million in federal funds have been matched by over $1.08 billion in local, university, and private sector funds. With the oldest institute only four years old, direct economic impact is difficult to measure. However, the general consensus is that NNMI is successful with more than a two for one return on federal funds invested. There are several federal agencies involved in the NNMI program including the Departments of Commerce, Defense, Energy, Education, Agriculture, National

Aeronautics and Space Administration (NASA), the National Science Foundation and six interagency committees.[145]

The theories of Michael Porter of Harvard and Bruce Katz of Brookings Institute may help predict the success of future institutes. Michael Porter's 1990 cluster theory defines clusters as geographic concentrations of companies, suppliers, support services, financiers, specialized infrastructure, producers of related products, and specialized institutions that give competitive strengths through shared advantages.[146] Bruce Katz refined that theory starting in 2010 with innovation districts—physically compact, transit accessible geographic areas where anchor institutions cluster and connect with startups, business incubators, and accelerators. Innovation districts differ from clusters in that they thrive from mixed use—housing, office, and retail.[147]

A historical study of the successful clusters yielded several valuable insights. Startups are more likely to succeed where a concentration of serial entrepreneurs and venture capital exists. Business incubators and accelerators offer no competitive advantage to startups. There is no tangible benefit to collocating SMEs on a (science / technology / research) park campus versus in a cluster. Proximity to and the proper relationship with research universities can be worth up to a $300,000 annually for SMEs.[148] Geographical location within the United States can affect by up to 20% whether a college graduate is likely to seek employment in the area.[149] Collocated suppliers are not the best model for all SMEs, depending on complexity and market demand on good produced.[150]

Cluster and innovation district theories show that future institutes may be successful for biotechnology in Cleveland, San Francisco, or Oklahoma City. Likewise, Albuquerque, Portland, Austin, Chattanooga, and Buffalo are all metropolitan areas ripe for innovation district development. Finally, in addition to the NMMI initiatives, there are other federally funded regional cluster and innovation. Specifically, the Small Business Administration, Economic Development Administration, and Environmental Protection Agency all maintain cluster and regional innovation programs that fund and track clusters.

Recommendations

1. The National Network for Manufacturing Innovation (NNMI) is an effective program. It should remain in place with the following caveats.

a. The next institutes awarded should be focused on the Advanced Manufacturing disciplines not already addressed - *Nanomanufacturing*; *Biomanufacturing and Bioinformatics*; I*ndustrial Robotics* and *Advanced Ceramics*.

b. Institute grading criteria (for awarding) should be reviewed to ensure it includes business incubation / acceleration; access to venture capital; and regional factors such as student migration, cost of living, and access to transportation, among other items.

c. Future institutes should – if a competitive bid is submitted – be located in an area that already has a cluster with an anchor in place, and in a developing urban area.

2. The federal funding available to both small and medium enterprises (SME) and members of institutes should be reviewed to reduce redundancy. In addition to the Departments (Commerce, Defense, Energy, Education, Agriculture), NASA, the National Science Foundation and six interagency committees that are directly involved in the NMMI program, the Small Business Administration, Economic Development Administration, Environmental Protection Agency, and the Department of Labor all fund programs designed to stimulate innovation and regional development.

Essay #5

Additive Manufacturing Implementation at the Service Level: A Proposed Way Forward

Although additive manufacturing has existed for decades, the capability is experiencing a surge in popularity based on several initiatives to either create or re-shore manufacturing capabilities in the U.S. Some of this new found enthusiasm is being driven by the Government infusing endorsements and dollars into additive manufacturing, encouraging public, private and state university ventures. Many of these collaborations are achieved through a Co-Operative Agreement between a Governmental organization and the entity, under the National Network for Manufacturing Innovation (NNMI) to encourage manufacturing in the U.S.

The potential exists for implementing additive manufacturing at the individual military service level. The case takes a detailed approach to the necessary steps in formalizing the process for the introduction of an additive manufacturing capability at the DoD service level. While introducing additive manufacturing could be achieved in any or all of the services, this essay assumes the Navy is designated Executive Agent for ease of lexicon and in presenting specific examples. The essay takes an in-depth look at a three tiered approach in additive manufacturing implementation focusing on 1) *Inception and Program Roll out, 2) Managing & Growing the capability and 3) Sustainment and Evolution*. Effectively managing this capability will have positive effects on the resource element of national security.

Recommendation

The strategic recommendation is that the Government should establish a Program Office and create an additive manufacturing Program of Record (POR). Through establishing a POR, the Navy could create a choke-point between a customer generating a requirement and the inventory control point (ICP) which normally satisfies the demand signal. Creating an additive manufacturing capability overseas in a strategic location would enable the Navy to screen requirements for additive manufacturing fulfillment prior to releasing to an ICP, thereby reducing inventory levels, increasing mission readiness, shortening the supply chain and avoiding costs.

Essay #6

Department of Defense Workers: Connecting National Certificates to Service Schools

Skills learned through military training must be better documented through the use of national manufacturing certifications. National Association of Manufacturing (NAM) endorsed certificates are part of a scalable, nationally portable certification system. The military services use a website called "Credentialing Opportunities On-Line" (COOL), which compares military occupational skills to various credentials. Several NAM endorsed certificates are available for service members through COOL, but the current system requires service members to either take a certification course outside of the military or a private certification exam. Additionally, the foundational NAM-endorsed certificate (e.g. National Career Ready Certificate) is not part of the COOL program. Certificates that cut across multiple sectors of manufacturing, like the "Manufacturing Skill Standards Council" (MSSC) Certified Production Technician (CPT) are associated with very few military occupations. This results in a lack of a civilian certification that documents what veterans learned through military training. In the case of the Navy, only one military occupation qualifies for credit towards the CPT certificate. CPT is described as consisting "of five individual certificate modules: Safety; Quality Practices & Measurement; Manufacturing Processes & Production; Maintenance Awareness; and Green Production."[151] Based on this description, multiple other military repair and maintenance jobs should qualify for credit towards a CPT certification. The current methodology for validating military job occupations against certification programs[152] is failing to match most military jobs to equivalent civilian certificates. The result is that service members are unable to seamlessly leave the military and obtain civilian employment.

Recommendation

Better align skills learned through official military courses and on the job training with existing manufacturing certifications. Intent would be for the DoD Service components to have the capability to award certification upon successful completion of military courses.

Essay #7
Is Right to Work (RTW) Good or Bad for American Manufacturing?

RTW refers to state legislation that prohibits businesses and unions from reaching agreements (i.e., union security clauses) that require all workers, not just union members, to pay union dues.[153] Recent studies show RTW legislation has a negative impact on employee compensation which in turn has a negative impact on the education of the workforce at a time when advanced manufacturing technologies require a better educated workforce.[154] These effects are due to RTW's negative effect on union membership which results in less political influence and fewer resources to protect employee benefits gained through their collective bargaining efforts over the years.[155] To assist employees in regaining some of the benefits of collective bargaining in the absence of unions, without degrading American competitiveness, the Federal Government can change the Federal labor laws and corporate tax code to mandate publicly owned businesses establish and utilize employee councils as an alternative form of collective bargaining; cap executive compensation to free up resources for improving competitiveness; and incentivize businesses through tax credits to undertake activities that lead to sustainable growth like R&D, training & education, capital investments to enhance productivity, etc. In conjunction with these Federal level changes, State and local governments must work to align educational programs with workforce requirements and develop affordable degree programs so workers can acquire the required knowledge and skills to compete or retain jobs employing advanced manufacturing technologies. The timing is right to undertake these changes and actions given taxpayer frustration with income inequality, the high cost of education and what they perceive as a weakened America. In response to this frustration, both Republican and Democratic presidential candidates alike have addressed one or more of these issues while campaigning for the upcoming 2016 Presidential Election. The bottom line is that the negative effects of RTW legislation must be addressed if advanced manufacturing technologies are going to assist in improving American competitiveness in this global economy.

Essay #8
Structure of Innovation: An Historical Example

In the 1950s, the United States Air Force established an independent bureaucratic structure that promoted collaborative innovation. The agency, which eventually became known as Air Force Systems Command (AFSC), ushered in an innovative approach to materiel design and acquisition through a formal relationship between the military, industry, and academia. This framework provides a model to promote today's defense industrial base.

AFSC implemented a systems management approach to revolutionize the acquisitions process.[156] This advancement, however, required the sponsorship of innovative leaders such as General Bernard Schriever and Lieutenant General Jimmy Doolittle.[157] The two men's unconventional career path helped them develop critical relationships with industry and academia. The resulting collaboration produced innovative machines of war that enabled American's Cold

War defense policy. For instance, Schriever's Intercontinental Ballistic Missile (ICBM) fleet provided a crucial element of nuclear deterrence. The "first offset" underscored President Dwight D. Eisenhower's new look strategy. Likewise, AFSC developed fourth-generation fighters, precision weapons, and stealth technology.[158] The emergence of the "second offset" advanced the demise of the Soviet Union.[159]

Recommendation

The DoD should emulate the lessons of AFSC and support independent R&D organizations. The agency should also advance policies that structurally promote interaction between the military, industry, and academic universities. The new Defense Innovation Unit-Experimental located in Silicon Valley is an encouraging start.[160] The DoD should expand the initiative in other technical hubs across America and staff them with upwardly mobile military officers. Finally, the services should foster strong, open-minded military leaders that can implement change within the government bureaucracy. Combined, these policies provide a roadmap to realizing the third offset and innovation within America's defense industrial base.

Essay #9

How does Advanced Manufacturing Affect U.S. National Security?

Advanced manufacturing not only maintains positive implications for society, but also strengthens national security.[161] Because advanced manufacturing creates superior-quality jobs, provides the nation with innovative finished products, provides critical goods used in military operations and the intelligence community, advanced manufacturing is considered to be a vital national security interest. Therefore, devoting significant Congressional focus, corporate focus and even educational focus on advanced manufacturing principles, funding and processes ensures that a nation can not only defend and protect itself, but also maintain economic growth that is vital to a stable and thriving national economy.

Advanced manufacturing capabilities in areas of national defense and offensive weaponry also make it possible to produce much larger volumes of finished product. Firms that have achieved economies of scale through years of advanced manufacturing capability (achieved through massive revenue production related to its goods), have the ability to amortize fixed overhead, thus reducing costs of manufacture in the long-term.[162] To produce products with strategic national defense capabilities requires substantial capital; hence advanced manufacturing maintains this ability for capital production in a capacity far greater than generic manufacturing processes at firms with less-developed manufacturing systems. Advanced manufacturing, for the U.S., is vital for sustaining its hegemonic position in the world today and, without this competency, the country would likely maintain substantial issues in backing any intimidating warnings against hostile and irrational foreign powers; a factor that underpins a great deal of U.S. foreign policy today against such antagonistic foreign governments. The ability of foreign countries to buy American products, especially the military, strengthens the economy and increases competition among manufacturing companies for innovation, which will have a positive effect on the industry in general. However, the difficult procedures and complex laws through commissions selling military products to foreign countries (FMS), which may take many years for approval the sale, affects a significant negative impact on U.S. manufacturers as well as on the U.S. economy in general and often leads potential buyers to another country.

APPENDIX

APPENDIX A: Tables

Method used to layer material	Description
Material extrusion	Material is selectively dispensed through a nozzle or orifice
Material jetting	Droplets of build material are selectively deposited
Binder jetting	Liquid bonding agent is selectively deposited to join powder materials
Sheet lamination	Sheets of material are bonded to form an object
Vat photopolymerization	Liquid photopolymer in a vat is selectively cured by light-activated polymerization
Powder bed fusion	Thermal energy selectively fuses regions of a powder bed
Directed energy deposition	Focused thermal energy is used to fuse materials by melting as the material is being deposited

Table 1: Categories of Additive Manufacturing[163]

Name	Gov't Lead	Manufacturing Technology Focus	Location	Award Announced
America Makes	DoD	Additive Manufacturing	Youngstown, OH	August 2012
Digital Manufacturing and Design Innovation Institute (DMDII)	DoD	Visualization, Informatics, and Digial Manufacturing Technologies	Chicago, IL	February 2014
Lightweight Innovations for Tomorrow (LIFT)	DoD	Advanced Materials Design, Synthesis, and Processing	Detroit, MI	February 2014
PowerAmerica	DoE	Sustainable Manufacturing	Raleigh, NC	December 2014
The Institute for Advanced Composites Manufacturing Innovation (IACMI)	DoE	Advanced Materials Design, Synthesis, and Processing	Knoxville, TN	June 2015
American Institute for Manufacturing Integrated Photonics (AIM Photonics)	DoD	Advanced Manufacturing and Test Equipment	Rochester, NY	July 2015
NextFlex	DoD	Flexible Electronics Manufacturing	San Jose, CA	August 2015
Advanced Functional Fabrics of America (AFFOA)	DoD	Advanced Forming and Joining Technologies	Cambridge, MA	April 2016
Clean Energy Manufacturing Innovation Institute on Smart Manufacturing: Advanced Sensors, Controls, Platforms, and Modeling for Manufacturing	DoE	Advancing Sensing, Measurement, and Process Control	TBD	June 2016 (Proposals Due)

Table 2: NNMI Manufacturing Innovation Institutes[164]

APPENDIX B: Additive Manufacturing Technologies and 3D Printer Vendors[165]

3D printer vendors use different technologies based on the type of material and the method used to deliver the material

Material Method	Technology	Example Materials
Extrusion	Fused Deposition Modeling (FDM)	Thermoplastics, eutectic metals, edible materials
Extrusion	Bio Printing	Biological tissues
Extrusion	Liquid Extrusion	Food (cheese, chocolate, etc.), concrete
Wire	Electron Beam Freeform Fabrication	Almost any metal alloy
Granular	Electron Beam Melting (EBM)	Titanium alloys
Granular	Selective Laser Sintering (SLS)	Thermoplastics, metal powders, ceramic powders
Granular	Direct Metal Laser Sintering	Almost any metal alloy
Granular	Powder Bed and Inkjet Head 3D Printing	Plaster
Granular	Candyfab	Sugar
Laminated	Laminated Object Manufacturing (LOM)	Paper, metal foil, plastic film
Light	Stereolithography	Photopolymers
Light	Digital Light Processing	Photopolymers

Selected Major 3D Printer System Vendors

Company	Geo	Primary Technology	Materials
3D-Systems	US, AUS, NED, ITA	Binder jetting, material jetting, vat photopolymerization, powder bed fusion, material extrusion	Metal, polymer
Arcam	SVE	Powder bed fusion	Metal (titanium)
DM3D Technology	US, AUS, NED, ITA	Directed energy deposition	Metal
Envisiontec	GER, US	Vat photopolymerization	Polymer
EOS	GER	Powder bed fusion	Ceramic, metal, polymer
ExOne	US, GER, JPN	Binder jetting	Ceramic, metal, polymer
Fabrisonic	US	Sheet lamination	Metal
MakerBot	US, Europe, AP	Material extrusion	Polymer
Optomec	US	Directed energy deposition	Metal
Phenix Systems	FRA	Powder bed fusion	Ceramic, metal
RepRap	UK	Material extrusion	Polymer
Stratasys	US, GER, IND, AP	Material extrusion, material jetting	Polymer, metal, ceramic
Voxelijet	GER	Binder jetting	Ceramic, metal, polymer

Appendix C: Additive Manufacturing Technologies, Corresponding Base Materials, and Advantages and Disadvantages[166]

Technology	Process	Typical Materials	Advantages	Disadvantages
Stereolithography	Vat polymerization	Liquid photopolymer, composites	Complex geometries; detailed parts; smooth finish	Post-curing required; requires support structures
Digital light processing	Vat polymerization	Liquid photopolymer	Allows concurrent production; complex shapes and sizes; high precision	Limited product thickness; limited range of materials
Multi-jet modeling (MJM)	Material jetting	Photopolymers, wax	Good accuracy and surface finish; may use multiple materials (also with color); hands-free removal of support material	Range of wax-like materials is limited; relatively slow build process
Fused deposition modeling	Material extrusion	Thermoplastics	Strong parts; complex geometries	Poorer surface finish and slower build times than SLA
Electron beam melting	Powder bed fusion	Titanium powder, cobalt chrome	Speed; less distortion of parts; less material wastage	Needs finishing; difficult to clean the machine; caution rquired when dealing with X-rays
Selective laser sintering	Powder bed fusion	Paper, plastic, metal, glass, ceramic, composites	Requires no support structures, high heat and chemical resistant; high speed	Accuracy limited to powder particle size; rough surface finish
Selective heat sintering	Powder bed fusion	Thermoplastic powder	Lower cost that SLS; complex geometries; no support structures required; quick turnaround	New technology with limited track record
Direct metal laser sintering	Powder bed fusion	Stainless steel, cobalt chrome, nickel alloy	Dense components; intricate geometries	Needs finishing; not suitable for large parts
Powder bed and inkjet head printing	Binder jetting	Ceramic powders, metal laminates, acrylic, sand, composites	Full-color models; inexpensive; fast to build	Limited accuracy; poor surface finish
Plaster-based 3D printing	Binder jetting	Bonded plaster, plaster composites	Lower price; enables color printing; high speed; excess powder can be reused	Limited choice of materials; fragile parts
Laminated object manufacturing	Sheet lamination	Paper, plastic, metal, laminates, ceramics, composites	Relatively less expensive; no toxic materials; quick to make big parts	Less accurate; non-homogenous parts
Ultrasonic consolidation	Sheet lamination	Metal and metal alloys	Quick to make big parts; faster build speed of newer ultrasonic consolidation systems; generally non-toxic materials	Parts with relatively less accuracy and inconsistent quality compared to other processes; need for post-processing
Laser metal deposition	Direct energy deposition	Metal and metal alloys	Multi-material printing capability; ability to build large parts; production flexibility	Relatively higher cost of systems; support structures are required; need for post-processing activities to obtain smooth finish

APPENDIX D: Additional Information on Organizations Visited During Field Studies

Note: The Executive Summary portion of Appendix D above was derived from each organization's official website.

Field Studies - Domestic		
Organization	**Website**	**Executive Summary**
Applied Rapid Technologies Corporation, Fredericksburg, VA	http://www.artcorp.com/	A rapid prototyping company that provides leading-edge Stereolithography and Polyjet printing technology to assist entrepreneurs in creating first stage prototypes and short-run production parts.
National Institute of Standards and Technology, US Dept of Commerce, Gaithersburg, MD	http://www.nist.gov/	Founded in 1901, NIST is a non-regulatory federal agency within the U.S. Department of Commerce. NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.
PowerAmerica Institute (aka Next Generation Power Electronics National Manufacturing Innovation Institute), Raleigh, NC	www.poweramericainstitute.org/	Backed by $70 million from the U.S. Department of Energy over five years, they are working to make the wide bandgap semiconductor technologies cost-competitive with silicon-based power electronics and reduce the perceived risk in their adoption in numerous industries.
Air Force Research Laboratory, Dayton, OH	http://www.wpafb.af.mil/AFRL/	The Air Force Research Laboratory is a global technical enterprise, boasting some of the best and brightest leaders in the world. They are Revolutionary, Relevant, and Responsive to the Warfighter. AFRL defends America by unleashing the unconquerable power of scientific and technical innovation. Their mission is leading the discovery, development, and integration of affordable warfighting technologies for our air, space, and cyberspace force.
Air Force Material Command, Dayton, OH	http://www.afmc.af.mil/	With headquarters at Wright-Patterson Air Force Base, Ohio, Air Force Materiel Command (AFMC) conducts research, development, test and evaluation, and provides acquisition management services and logistics support necessary to keep Air Force weapon systems ready for war.

Field Studies – Domestic (continued)		
Organization	**Website**	**Executive Summary**
America Makes (aka National Additive Manufacturing Innovation Institute), Youngstown, OH	https://americamakes.us	As the national accelerator for additive manufacturing (AM) and 3D printing (3DP), America Makes is the nation's leading and collaborative partner in AM and 3DP technology research, discovery, creation, and innovation.
Digital Manufacturing and Design Innovation Institute, Chicago, IL	http://dmdii.uilabs.org/	The Digital Manufacturing and Design Innovation Institute is a unique public-private partnership acting as a world-class, first-of-its-kind manufacturing hub. The Institute has the capabilities, innovative spirit and collaborative expertise to transform American manufacturing.
Argonne National Laboratory, Argonne, IL	http://www.anl.gov/	Argonne is a multidisciplinary science and engineering research center, where "dream teams" of world-class researchers work alongside experts from industry, academia and other government laboratories to address vital national challenges in clean energy, environment, technology and national security.
Boeing, Everett, WA	http://www.boeing.com	Boeing Commercial Airplanes, a business unit of The Boeing Company, is committed to being the leader in commercial aviation by offering airplanes and services that deliver superior design, efficiency and value to customers around the world.
MTorres America, Bothell, WA	http://www.mtorres.es/en	The MTorres group is an industrial organization, qualified in advanced technology to develop high-complexity innovative solutions in industrial process automation for customer identified problems. MTorres serves as a partner and supply chain provider to the Boeing Corporation.
Blue Origin, Kent, WA	https://www.blueorigin.com/	A space exploration company developing ground-breaking spaceflight systems with a culture of innovation, and leverage advanced manufacturing techniques when practical to advance space exploration.

Field Studies – Domestic (continued)		
Organization	**Website**	**Executive Summary**
The Museum of Flight, Seattle, WA	https://www.museumofflight.org	The Museum of Flight exists to acquire, preserve, and exhibit historically significant air and space artifacts, which provide a foundation for scholarly research, and lifelong learning programs that inspire an interest in and understanding of science, technology, and the humanities.

Field Studies - International		
Organization	**Website**	**Executive Summary**
Mutual Defense Assistance Office, Embassy of the United States, Tokyo, Japan	http://japan.usembassy.gov/e/tmdao-main.html	The Mutual Defense Assistance Office (MDAO) is a joint service organization that facilitates defense equipment and technology exchanges between the governments and industries of Japan and the United States
Political-Military Affairs Unit, Embassy of the United States, Tokyo, Japan	http://japan.usembassy.gov/e/info/tinfo-pol-mil.html	Works closely with U.S. military counterparts, the Political-Military Affairs Unit ("Pol-Mil Unit") handles all issues associated with the U.S. military presence in Japan, as well as long-term political-military issues related to the U.S.-Japan security relationship
Trade and Economic Policy Unit, Embassy of the United States, Tokyo, Japan	http://japan.usembassy.gov/e/info/tinfo-econ-trade.html	The Trade and Economic Policy Unit manages trade issues and policy advocacy including: Service industries (insurance, maritime, civil aviation, and distribution), Basic industry (autos and parts, glass, paper), Government procurement High technology industries (computers, supercomputers, semiconductors, satellites), and Intellectual property issues.

Field Studies – International (continued)		
Organization	**Website**	**Executive Summary**
Asian Office of Aerospace Research and Development, Air Force Office of Scientific Research, Air Force Research Laboratory, Tokyo, Japan	http://www.wpafb.af.mil/	The Asian Office of Aerospace Research and Development (AOARD), in Tokyo, Japan, has an area of responsibility that includes Asia, India, and Pacific Rim countries, including Australia and New Zealand; the Southern Office of Aerospace Research and Development (SOARD), in Santiago, Chile, provides coverage throughout the Latin American region; and the International Office North (AFOSR/ION), as part of AFOSR in Arlington, VA, serves as the Washington DC liaison for AFOSR's international activities.
Ministry of Economy, Trade and Industry, Tokyo, Japan	http://www.meti.go.jp/english/	In 1949, the Ministry of Commerce and Industry was reorganized and the Ministry of International Trade and Industry was established.Its internal subdivisions consisted of eight bureaus: Minister’s Secretariat, Trade Bureau, Trade Promotion Bureau, Enterprise Trade Bureau, Textile Trade Bureau, General Merchandise Trade Bureau, Machinery Trade Bureau, Chemical Trade Bureau, and Iron and Steel Trade Bureau.
Cross-ministerial Strategic Innovation Promotion Program (SIP), Council for Science, Technology and Innovation, Tokyo, Japan	http://www.nagai.iis.u-tokyo.ac.jp/sip/aboutus/sip.htm	The Cross-ministerial Strategic Innovation Promotion Program (SIP) is a Japanese project led by the Cabinet Office's Council for Science, Technology and Innovation. The project was founded to promote scientific and technical innovation through management that extends beyond the boundaries of existing fields and government departments, ministries and agencies.

Field Studies – International (continued)		
Organization	**Website**	**Executive Summary**
Acquisition, Technology and Logistics Agency (ATLA), Ministry of Defense, Tokyo, Japan	http://www.mod.go.jp/atla/en/soubichou_gaiyou.html	To secure technological dominance under the increasingly severe security environment surrounding Japan, and to deliver the superior equipment in such environment, ATLA will grasp trends in advanced technologies, formulate a technological strategy which sets forth the direction for future Research and Development (R&D) based on the trends, cooperate with various R&D organizations in Japan and overseas, apply advanced dual-use technologies, and thus enhances technological capabilities through R&D projects.
FANUC Corporation, Oshino-mura, Yamanashi Prefecture, Japan	http://www.fanuc.co.jp/en/contact/index.htm	FANUC has consistently pursued the automation of factories since 1956, when it succeeded in the development of the SERVO mechanism for the first time in the Japanese private sector.FANUC contributes to the promotion of automation for customers, with the three pillars consisting of the FA Business Division, based on its basic technologies of NC and SERVO, and the ROBOT Business Division and ROBOMACHINE Business Division which apply these basic technologies.
Mitsubishi Aircraft Corporation, Mitsubishi Heavy Industries (MHI), Nagoya, Aichi Prefecture, Japan	https://www.mhi-global.com	MHI is a Japanese multinational engineering, electrical equipment, and electronics company headquartered in Tokyo, Japan. MHI's products include aerospace components, air conditioners, aircraft, automotive components, forklift trucks, hydraulic equipment, machine tools, missiles, power generation equipment, ships, and space launch vehicles.[2] Through its defense-related activities it is the world's 23rd-largest defense contractor measured by 2011 defense revenues, and the largest based in Japan.

APPENDIX E: Advanced Manufacturing Program Description[167]

ADVANCED MANUFACTURING (MAN): Brilliant manufacturing, disruptive manufacturing, high velocity manufacturing, innovation hubs; all of these phrases have been used to describe Advanced Manufacturing. Manufacturing itself is an enabling technology which underpins and supports any number of defense and industrial sectors. As such, it is critical to the national economy and to national defense. The Department of Defense has a longstanding interest in the sector, as both a developer of advanced manufacturing technology, and a customer of manufactured products. Advanced technology and innovation are underpinnings of defense, and are the basis of the Department's Third offset strategy.

This IS will examine a number of the disruptive technologies that make up Advanced Manufacturing. These include:

- The manufacturing version of the internet of things; the embedding of sensors in parts, machines and products, both on and off the factory floor, which allows the transmission of information, and the integration of machines, products, maintenance, as well as speed and traceability;
- Additive manufacturing (3D Printing), or the use of digitization to create tangible goods in in real time, and in distributed or diverse locations;
- Robotics and human, machine interfaces;
- Big data and advanced analytics.

These and many more will be a source off innovation and strength for those countries and companies that can take advantage of these disruptions, but will also pose a threat to those entities that cannot participate in the innovation boom.

The IS will examine the role of global and domestic governments (national, state and local) in this innovative and disruptive field. How, and when, are innovative technologies started, spread and implemented across industries? What role and interest does the Defense Department have in the development of innovative and disruptive technologies? How and when does industry participate and lead in this effort? What, if any national policies are necessary and sufficient to foster advanced manufacturing innovation? Will there be winners and losers? Domestically? Globally? By company?

We will examine the alliances between academia, government and industry that work together to allow the development, growth and diffusion of advanced technologies. We will visit Federal labs, where advances in additive manufacturing are taking place, we will visit companies who are recreating themselves around brilliant manufacturing, and academia, where research and development are taking place, and workers capable of working in advanced manufacturing are being educated and trained. We will examine Innovation Hubs, where effective synergy takes place.

ENDNOTES

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[1] "Innovation Quotes," *BrainyQuote*, accessed May 12, 2016, http://www.brainyquote.com/quotes/keywords/innovation.html, 1.

[2] "Rosie the Riveter," *History*, accessed May 12, 2016, http://www.history.com/topics/world-war-ii/rosie-the-riveter.

[3] Oliver Joy, "What does it mean to be a digital native?," CNN, last updated December 8, 2012, accessed May 12, 2016, http://www.cnn.com/2012/12/04/business/digital-native-prensky/index.html. The post-millennial "digital native," a term coined by U.S. author Marc Prensky in 2001, is emerging as the globe's dominant demographic, while the "digital immigrant" becomes a relic of a previous time. The digital native-immigrant concept describes the generational switchover where people are defined by the technological culture which they're familiar with. Prensky defines digital natives as those born into an innate "new culture" while the digital immigrants are old-world settlers, who have lived in the analogue age and immigrated to the digital world. Although not Luddites, the immigrants struggle more than natives to adapt to hi-tech progress.

[4] "NNMI," Manufacturing.gov: A National Advanced Manufacturing Portal, accessed May 1, 2016, https://www.manufacturing.gov/nnmi/ and Consolidated and Further Continuing Appropriations Act, 2015, H.R. 83, 113th Cong., 2d sess. (January 3, 2014), 91-2, accessed May 1, 2016, https://www.gpo.gov/fdsys/pkg/BILLS-113hr83enr/pdf/BILLS-113hr83enr.pdf.

[5] President's Council of Advisors on Science and Technology, "Report to the President on Ensuring American Leadership in Advanced Manufacturing," Executive Office of the President (June 2011), ii, accessed April 9, 2016, https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-advanced-manufacturing-june2011.pdf.

[6] Triple Helix Research Group, "The Triple Helix concept," Stanford University, accessed May 12, 2016, http://triplehelix.stanford.edu/3helix_concept.

[7] Energetics Incorporated, "Measurement Science Roadmap for Metal-Based Additive Manufacturing," National Institute for Standards and Technology (May 2013), vii and Marc Trachtenberg, "3D Printing 101 – It's not just for Chotchkies," (paper presented at the 3D Printing/Additive Manufacturing: Cutting-Edge IP and Business Implications conference of the International Trademark Association, New York City, NY, March 10-11, 2015), 3. To provide a more descriptive explanation of additive manufacturing, Team AdMan combined the additive manufacturing descriptions provided in these two sources.

[8] Team AdMan based this conclusion on the synthesis of material obtained from a variety of open sources and observations made during field studies.

[9] "NNMI," Manufacturing.gov: A National Advanced Manufacturing Portal.

[10] Jill M. Hruby, Dawn K. Manley, Ronald E. Stoltz, Erik K. Webb and Joan B. Woodward, "The Evolution of Federally Funded Research & Development Centers," *Public Interest Report* 64, no. 1 (Spring 2011): 24 and 31, accessed May 10, 2016, http://fas.org/pubs/_docs/2011Spring-PIR-hires.pdf.

[11] Marc Levinson, "U.S. Manufacturing in International Perspective," Congressional Research Service, April 26, 2016, summary, accessed May 12, 2016, http://fas.org/sgp/crs/misc/R42135.pdf. Reference also applies to previous sentence. Estimates are based on the value of each country's manufacturing in U.S. dollars; part of the decline in the U.S. share was due to a 23% decline in the value of the dollar between 2002 and 2011 (to 16.5%) and part of the rise since 2011 is attributable to a stronger dollar.

[12] "Top 20 Facts about Manufacturing," National Association of Manufacturers, accessed May 10, 2016, http://www.nam.org/Newsroom/Top-20-Facts-About-Manufacturing/ and Consolidated and Further Continuing Appropriations Act, 2015, 91.

[13] Consolidated and Further Continuing Appropriations Act, 2015, 91 and The World Factbook, "Country Comparison :: GDP (Official Exchange Rate)," Central Intelligence Agency, accessed May 15, 2016, https://www.cia.gov/library/publications/the-world-factbook/rankorder/2195rank.html. This comparison uses $2.03 trillion figure for 2012 for the amount manufacturers contributed to the economy from the appropriations act and compares that amount to The World Factbook 2013 (estimated) data for Gross Domestic Product (GDP).

[14] "Top 20 Facts about Manufacturing," National Association of Manufacturers.

[15] Bureau of Labor Statistics, "Employment, Hours, and Earnings from the Current Employment Statistics survey (National)," U.S. Department of Labor, accessed May 10, 2016, http://data.bls.gov/timeseries/CES3000000001. Based on annual averages of labor employment between 1970 and 2016 for the series "All employees, thousands, manufacturing, seasonally adjusted."

[16] "Top 20 Facts about Manufacturing," National Association of Manufacturers.

[17] Consolidated and Further Continuing Appropriations Act, 2015, 91.

[18] Craig Giffi, Jennifer McNelly, Ben Dollar, Gardner Carrick, Michelle Drew, and Bharath Gangula, "The skills gap in U.S. manufacturing: 2015 and beyond," sponsored by The Manufacturing Institute and Deloitte, 5, accessed May 19, 2016, http://www.themanufacturinginstitute.org/~/media/827DBC76533942679A15EF7067A704CD.ashx.

[19] As one example, the manufacturing competency models for "Mechatronics" and "Aviation" both require "Science" skills. Yet, the specific science skills required differ between the two competencies. See "Mechatronics," Competency Model Clearinghouse, accessed April 16, 2016, http://www.careeronestop.org/CompetencyModel/blockModel.aspx?tier_id=2&block_id=567&ME=Y and "Aerospace," Competency Model Clearinghouse, accessed April 16, 2016, http://www.careeronestop.org/CompetencyModel/blockModel.aspx?tier_id=2&block_id=395&AEO=Y.

[20] Giffi, McNelly, Dollar, Carrick, Drew, and Gangula, "The skills gap in U.S. manufacturing: 2015 and beyond," 15.

[21] Yuwei Zhai, Diana A. Lados, and Jane L. LaGoy, "Additive Manufacturing: Making Imagination the Major Limitation," *JOM: The Journal of the Minerals, Metals & Materials Society* 66, no. 5 (May 2014): 809, accessed April 8, 2016, http://link.springer.com/article/10.1007%2Fs11837-014-0886-2. The authors wrote: "Modern [Additive Manufacturing] technology, symbolized by stereolithography (SL), found its origin in a system proposed by Munz in 1951. In Munz's system, a layer of transparent photopolymer was selectively exposed and hardened according to the cross-section of a scanned object using a piston mechanism."

[22] "Apparatus for production of three-dimensional objects by stereolithograph," accessed May 20, 2016, http://www.google.com/patents/US4575330.

[23] Though technically not considered a formal additive manufacturing process, the manufacturing of the composite materials Boeing uses to build the wings and fuselages on their 787 and, in the future, the wings on their 777X involves a layering process. Thus, in a sense, Boeing has used additive manufacturing (aided by 30 years of composite materials research and development) to manufacture commercial airliners for years. This note is based on information received during the Team AdMan visit to Boeing's Advanced Development Composites Center.

[24] Additive Manufacturing Research Group, "The Seven Categories of Additive Manufacturing," Loughborough University, accessed April 18, 2016, http://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/. Team AdMan reached this conclusion regarding processes viable for metals additive manufacturing by selecting "Find out more here" and then selecting "Materials."

[25] Team AdMan based this conclusion on the synthesis of material obtained from a variety of open sources and observations made during field studies.

[26] United States Government Accountability Office, "3D Printing: Opportunities, Challenges, and Policy Implications of Additive Manufacturing," GAO-15-505SP (June 2015): 8 (for 2011 and 2013 data), accessed May 16, 2016, http://www.gao.gov/assets/680/670960.pdf and TJ McCue "Wohlers Report 2016: 3D Printing Industry Surpassed $5.1 Billion," Forbes, April 25, 2016, accessed May 16, 2016, http://www.forbes.com/sites/tjmccue/2016/04/25/wohlers-report-2016-3d-printer-industry-surpassed-5-1-billion/#5a3101107cb1 (for 2015 data).

[27] Carole Jacques, "3D Printing Market to Quadruple to $12 Billion in 2025," Lux Research, April 29, 2014, accessed April 16, 2016, http://www.luxresearchinc.com/news-and-events/press-releases/read/3d-printing-market-quadruple-12-billion-2025. In 2009, the expiration of several patents launched additive manufacturing into mainstream industry. Charles Hall's Stereo Lithography patent expired in 2004, but Scott Crump's Fused Deposit Modeling patent expiration in 2009 opened the market to increasingly less expensive technology as a number of firms were now able to enter the market. Sixteen additional patents held by U.S. companies 3D Systems, Stratasys, and DTM Corporation expired between 2013 and 2015 – essentially making additive manufacturing intellectual property a public good (Source: Pieter Van Lancker, "The influence of IP on the 3D printing evolution," Creax Blog, August 12, 2015, accessed, May 19, 2016, https://www.creax.com/en/our-work/the-3d-printing-evolution-insights-on-the-influence-of-ip-on-technology-dev).

[28] "Wohlers Report 2016 Published: Additive Manufacturing Industry Surpassed $5.1 Billion," Wohlers Associates, accessed May 16, 2016, https://wohlersassociates.com/press71.html.

[29] Jacques, "3D Printing Market to Quadruple to $12 Billion in 2025."

[30] Team AdMan based this conclusion on the synthesis of material obtained from a variety of open sources and observations made during field studies.

[31] Composites combine two or more different materials together.

[32] Team AdMan based this conclusion on the synthesis of material obtained from a variety of open sources and observations made during field studies.

[33] Team AdMan based this conclusion on the synthesis of material obtained from a variety of open sources and observations made during field studies.

[34] Levinson, "U.S. Manufacturing in International Perspective," summary. The author writes: "The Obama Administration has undertaken a variety of related initiatives, and Members [of Congress] have introduced hundreds of bills over many sessions of Congress intended to support domestic manufacturing activity in a variety of ways. The proponents of such measures frequently contend that the United States is by various measures falling behind other countries in manufacturing, and they argue that this relative decline can be mitigated or reversed by government policy."

[35] Office of Science and Technology Policy, "About PCAST," The White House, accessed April 18, 2016, https://www.whitehouse.gov/administration/eop/ostp/pcast/about.

[36] The reports are: Report to the President on Ensuring American Leadership in Advanced Manufacturing (2011), Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing (2012), National Network for Manufacturing Innovation: A Preliminary Design (2013), and Report to the President Accelerating U.S. Advanced Manufacturing (2014).

[37] President's Council of Advisors on Science and Technology, *Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing*, Executive Office of the President (July 2012), 7.

[38] Ibid., ix-xi. The recommendations under "enabling innovation" are: 1) Establish a National Advanced Manufacturing Strategy, 2) Increase R&D funding in top cross-cutting technologies, 3) Establish a National Network of Manufacturing Innovation Institutes (MIIs), 4) Empower enhanced industry/university collaboration in advanced manufacturing research, 5) Foster a more robust environment for commercialization of advanced

manufacturing, and 6) Establish a national advanced manufacturing portal. The recommendations under "securing the talent pipeline" are: 7) Correct public misconceptions about manufacturing, 8) Tap the talent pool of returning veterans, 9) Invest in community college level education, 10) Develop partnerships to provide skills certifications and accreditation, 11) Enhance advanced manufacturing university programs, and 12) Launch national manufacturing fellowships and internships. The recommendations under "improving the business climate" are: 13) Enact tax reform, 14) Streamline regulatory policy, 15) Improve trade policy, and 16) Update energy policy.

[39] "NNMI," Manufacturing.gov: A National Advanced Manufacturing Portal. Initial actions were taken via executive order. President Obama institutionalized the construct when he signed the Revitalize American Manufacturing and Innovation Act into law in December 2014. The AMNPO falls under NIST and the Department of Commerce.

[40] Ibid. and Jim McGuffin-Cawley, "Aspects of the Impact of America Makes on Laser-Based Additive Manufacturing," AmericaMakes, presentation give to Team AdMan on April 4, 2016, 6. The proposed schedule of NNMI expenditures referenced in these slides was pulled from Office of Management and Budget, *Fiscal Year 2014 Budget of the U.S. Government,* Executive Office of the President, April 2013, Table S-9, 203.

[41] "Institutes," Manufacturing.gov: A National Advanced Manufacturing Portal, accessed April 5, 2016, https://www.manufacturing.gov/nnmi-institutes/.

[42] Office of the Press Secretary, "We Can't Wait: Obama Administration Announces New Public-Private Partnership to Support," The White House, August 16, 2012, accessed May 16, 2016, https://www.whitehouse.gov/the-press-office/2012/08/16/we-can-t-wait-obama-administration-announces-new-public-private-partners.

[43] David L. Chandler, "New institute will accelerate innovations in fibers and fabrics," Massachusetts Institute of Technology, April 1, 2016, accessed May 16, 2016, http://news.mit.edu/2016/national-public-private-institute-innovations-fibers-fabrics-0401. Those contributing to the cost-sharing include the DoD, industrial partners, venture capitalist, universities, nonprofits, and states.

[44] Advanced Manufacturing Office, "2016 NIST NNMI Competition," National Institute for Standards and Technology, last updated May 19, 2016, accessed May 20, 2016, http://www.nist.gov/amo/nnmi/2016competition.cfm. Whatever the federal government puts up must be matched by the winning organization through private and/or non-federal dollars. Five years is the standard length of the co-operative agreements signed between the federal government and the winning organization.

[45] Triple Helix Research Group, "The Triple Helix concept."

[46] Richard Purcell, "Hagel's 'Third Offset Strategy' Key to Maintaining U.S. Military Supremacy," World Politics Review, December 29, 2014, accessed May 12, 2016, http://www.worldpoliticsreview.com/articles/14744/hagel-s-third-offset-strategy-key-to-maintaining-u-s-military-supremacy.

[47] Ibid. and Deputy Secretary of Defense Speech, "The Third U.S. Offset Strategy and its Implications for Partners and Allies," U.S. Department of Defense, January 28, 2015, accessed May 12, 2016, http://www.defense.gov/News/Speeches/Speech-View/Article/606641/the-third-us-offset-strategy-and-its-implications-for-partners-and-allies.

[48] Defense Innovation Unit Experimental, "Fact Sheet: Defense Innovation Unit – Experimental (DIUx): Silicon Valley," U.S. Department of Defense, accessed May 12, 2016, http://www.diux.mil/docs/DIUxFactsheet.pdf.

[49] Ibid. and Aaron Mehta, "DIUX Expands to Boston, with New Leadership," Defense News, May 11, 2016, accessed May 12, 2016, http://www.defensenews.com/story/defense-news/techwatch/2016/05/11/diux-expands-boston-new-leadership/84233338/.

[50] Manufacturing & Industrial Base Policy, "ManTech: The Defense Manufacturing Technology Program, U.S. Department of Defense (December 2015), 3.

[51] President's Council of Advisors on Science and Technology, "Report to the President on Ensuring American Leadership in Advanced Manufacturing," i.

[52] Ibid., 2.

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[66] Yen to $ conversion from google.com; no inflation or deflation considered.

[67] Cross-ministerial Strategic Innovation Promotion Program, "Pioneering the Future: Japanese Science, Technology and Innovation 2015," Council for Science, Technology and Innovation, 5.

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[69] Ibid., 7.

[70] Japan modeled this new defense equipment acquisition organization after the Office of the Secretary of Defense's Office of Acquisition, Technology, and Logistics (OSD/AT&L).

[71] Yen to $ conversion from google.com; no inflation or deflation considered.

[72] Yen to $ conversion from google.com; no inflation or deflation considered.

[73] Team AdMan obtained this information during field studies.

[74] Team AdMan obtained this information during field studies.

[75] This reluctance is a legacy of Japan's post-WWII reformations and "atonement" for its actions during World War II. Team AdMan learned about this challenge during field studies. For additional background, see Carl Pettit, "Why Japan is facing pressure to return to military research," *The Stack*, March 8, 2016, accessed May 23, 2016, https://thestack.com/world/2016/03/08/why-japan-is-facing-pressure-to-return-to-military-research/.

[76] Team AdMan based this conclusion on the synthesis of material obtained from a variety of open sources and observations made during field studies.

[77] Team AdMan based the conclusions in this and the previous sentence on non-attribution discussions that occurred during field studies. Independent responses from government, industry, and academia ranged from 3-5 to 5 to 5-10 years before advanced or additive manufacturing becomes commonplace. At least one of the responses referenced Gartner's Hype Cycle. Gartner Hype Cycles "provide a graphic representation of the maturity and adoption of technologies and applications, and how they are potentially relevant to solving real business problems and exploiting new opportunities" (Source: Research Methodologies, "Gartner Hype Cycle," Gartner, accessed May 16, 2016, http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp).

[78] Sharon Ford, "Additive Manufacturing Technology: Potential Implications for U.S. Manufacturing Competitiveness," *Journal of International Commerce and Economics* (September 2014): 25, accessed May 20, 2016, https://www.usitc.gov/journals/Vol_VI_Article4_Additive_Manufacturing_Technology.pdf.

[79] "Disruptive Technologies You Need To Know About Part 3," icreate, accessed May 16, 2016, http://icreate.org.in/wp/disruptive-technologies-you-need-to-know-about-part-3. The estimate, obtained from a McKinsey Global Institute analysis chart, focuses on the use of 3D printing to directly manufacture low-volume, high-value parts in the medical and transport manufacturing industries.

[80] Porosity is a term which is used to describe an important physical property of most materials. The porosity of a material is determined by measuring the amount of void space inside, and determining what percentage of the total volume of the material is made up of void space. Porosity measurements can vary considerably, depending on the material, and high or low porosity will impact the way in which the material performs. The property of porosity is actually slightly more complex than the simple percentage of void space inside a material. Another important consideration is the shape and size of the void spaces in the material. Another issue is the level of interconnection between void spaces (Source: "What is Porosity," wiseGEEK, accessed May 13, 2016, http://www.wisegeek.com/what-is-porosity.htm).

[81] Klaus Schwab, "The Fourth Industrial Revolution," *World Economic Forum*, accessed April 4, 2016, https://www.weforum.org/pages/the-fourth-industrial-revolution-by-klaus-schwab.

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[84] Giffi, McNelly, Dollar, Carrick, Drew, and Gangula, "The skills gap in U.S. manufacturing: 2015 and beyond," 5.

[85] Team AdMan based this conclusion on the synthesis of material obtained from a variety of open sources and observations made during field studies.

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[89] Team AdMan based this conclusion on the synthesis of material obtained from a variety of open sources and observations made during field studies.

[90] Ford, "Additive Manufacturing Technology: Potential Implications for U.S. Manufacturing Competitiveness," 23.

[91] Ibid., 22.

[92] Energetics Incorporated, "Measurement Science Roadmap for Metal-Based Additive Manufacturing," 5-6.

[93] Team AdMan based this conclusion on the synthesis of material obtained from a variety of open sources and observations made during field studies.

[94] Energetics Incorporated, "Measurement Science Roadmap for Metal-Based Additive Manufacturing," 5-6. Team AdMan observations made during field studies support and reinforce this conclusion.

[95] Giffi, McNelly, Dollar, Carrick, Drew, and Gangula, "The skills gap in U.S. manufacturing: 2015 and beyond," 5.

[96] Ibid., 10.

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[98] Craig Giffi, Jennifer McNelly, Ben Dollar, and Gardner Carrick, "Overwhelming Support: U.S. public opinions on the manufacturing industry," sponsored by The Manufacturing Institute and Deloitte, 2014, 10, accessed May 22,

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[105] Team AdMan based this conclusion on the synthesis of material obtained from a variety of open sources and observations made during field studies.

[106] Team AdMan based this conclusion on the synthesis of material obtained from a variety of open sources and observations made during field studies.

[107] Team AdMan based this conclusion on the synthesis of material obtained from a variety of open sources and observations made during field studies.

[108] Curt Woodward, “State of the Internet: U.S. Connection Speeds Rank 17th in World,” Xconomy, January 8, 2015, accessed May 14, 2016, http://www.xconomy.com/boston/2015/01/08/state-of-the-internet-us-connection-speeds-rank-17th-in-world/#.

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[164] Team AdMan created the table by pulling information from a variety of locations. The primary sources of information are available at: http://www.manufacturing.gov/nnmi-institutes/, https://www.whitehouse.gov/the-press-office/2016/04/01/fact-sheet-obama-administration-announces-new-revolutionary-fibers-and, and https://www.manufacturing.gov/energy-department-requests-proposals-for-new-institute-to-boost-efficiency-in-manufacturing/. All sites were accessed on May 15, 2016.

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