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Machining: A Summary of the Literature

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College of Urban Affairs
Center for Economic Development

Prepared for:
Ohio Manufacturing Institute

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June 2015

**MACHINING: A
SUMMARY OF THE
LITERATURE**

**CENTER FOR
ECONOMIC
DEVELOPMENT**

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INTRODUCTION

The Center for Economic Development at the Levin College of Urban Affairs at Cleveland State University prepared this report for the Ohio Manufacturing Institute (OMI) at The Ohio State University. The objective of this study is to provide background analysis of the machining industry for the OMI as they prepare a roadmap for the future and recommendations concerning this industry for the Ohio Development Services Agency (ODSA).¹

This report provides a literature review and summary of findings. Literature was collected and reviewed from various sources on the machining and machine tool industries. Academic articles, reports, and studies were collated and analyzed from databases, internet searches, and publications. The goal of this report is to provide a clear context of the state, national, and international conversation on the machining and machine tool industries, as well as to delineate opportunities and challenges as it related to these industries.

¹ This report was prepared with financial support from the State of Ohio. All contents of this report reflect the views of the Grantee and do not reflect the views of ODSA or that of the State of Ohio.

MACHINING OVERVIEW

Examining the industry profile of machine shops shows that this industry, “cuts raw materials into specified shapes and sizes using a variety of tools, such as lathes, milling machines, grinders and drill presses.”² This production process can use all types of raw materials including metal, plastics, and composite materials.³ The different types of machining are:⁴

- **Electrical Discharge Machining (EDM):** a machining process where instead of cutting the material, EDM melts or vaporizes it by discharging thousands of sparks to a metal workpiece. There are two main types of EDM: wire-cut and conventional.⁵
- **Electrochemical machining (ECM):** a machining process where pieces are machined by electrolytically dissolving the metal.⁶
- **Grinding:** a machining process where material is removed using an abrasive mechanism, usually a rotating wheel to remove material from a surface.⁷
- **Milling:** a machining process where a cylindrical cutting tool moves along multiple axes, and can create a variety of shapes, slots and holes.⁸
- **Drilling:** one of the most complex machining processes where the cutting and removal of metal is done by a drill.⁹
- **Turning:** a machining process conducted on a lathe. The difference between this type of machining and milling or drilling is that the workpiece spins while the cutting tool does not.¹⁰

MACHINE TOOL OVERVIEW

In addition to the machining industry, there is a machine tool industry, which is the industry that makes the machines that machine shops use to process material. The machine tool industry is important to manufacturing at large because without these machines, manufacturing cannot take place. The machine tool industry is essential to the success of any industrial economy. Moreover, improvements in this sector can have dramatic effects on overall manufacturing performance. Many consider the machine tool industry an issue of national defense because it is instrumental in the manufacturing of defense-related components.¹¹ In addition, it constitutes a sizable part of the U.S. economy. The 2014

² Morea, S. (2015, January). IBISWorld Industry Report 33271: Machine Shop Services in the US. *Ibis World*.

³ Ibid.

⁴ Ibid.

⁵ ThomasNet. (2015, June 12). Wire Cut EDM (Electrical Discharge Machining). Retrieved on June 12, 2015 from <http://www.thomasnet.com/articles/custom-manufacturing-fabricating/Wire-Cut-EDM>

⁶ EMAG. (2015). ECM - Electro-Chemical Machining Retrieved on June 12, 2015 from <http://www.emag.com/machines/applications/technologies/ecm-electro-chemical-machining/ecm.html>

⁷ Society of Manufacturing Engineers. (n.d). Basics of Grinding. *Fundamental Manufacturing Processes Video Series Study Guide*

⁸ ThomasNet. (2015, June 12). More about CNC Milling. Retrieved on June 12, 2015 from <http://www.thomasnet.com/about/cnc-milling-51276103.html>

⁹ AM Staff. (2010, May 24). Cutting Tool Applications, Chapter 8: Drills and Drilling Operations. American Machinist. Retrieved June 12, 2015 from <http://americanmachinist.com/machining-cutting/cutting-tool-applications-chapter-8-drills-and-drilling-operations>

¹⁰ (2015). Metal Cutting: Turning Machines. *Modern Machine Shop*. Retrieved June 12, 2015 from <http://www.mmsonline.com/zones/turning>

¹¹ Committee on the Machine Tool industry. (1983) *The U.S. Machine Tool Industry and the Defense Industrial Base*. Washington. D.C: National Academy Press.

Metalworking Capital Spending Survey by Gardner Research estimates that U.S. metalworking facilities will spend over \$7 billion on new metal-cutting equipment next year.¹²

Although the machine tool industry is an essential component of today's U.S. economy, it has had a rocky past, which is detailed in Finegold, et. al.'s "The Decline of the U.S. Machine-Tool Industry and Prospects for Its Sustainable Recovery."¹³ After the authors studied the historical importance of this industry in the United States and its decline in the 1980s, they suggested possible ways for this sector to regain its competitive advantage from overseas competitors. They have a host of recommendations, but in order to help machine-tool makers become more competitive, they recommend that the industry must:

1. Improve technology adoption within manufacturers and local networks that can provide services beyond the capacity of individual companies
2. Increase the industry's investment in the manufacturing infrastructure (i.e. basic research, transferable skills)
3. Shift U.S. trade policy from protecting the domestic market to creating a supportive environment for U.S. exports.

Other than Finegold, et. al.'s recommendation on U.S. trade policy, the current environment of the machine tool industry still struggles with the adoption of technology and their investment in the manufacturing infrastructure.

INDUSTRY TRENDS

Understanding the situation of machining within the supply-chain is key to understanding the overall industry environment. The machining industry traditionally lies as a Tier I or II supplier to larger manufacturing industries. Therefore, machining industries are customer-oriented businesses and rely on lead time to fulfil customer orders, require continuous improvement, shorter production lead-times, higher quality control, and increased machine tool utilization.

- **Continuous Improvement** - Industry trends that increase product demand, coupled with a competitive machining environment, has driven the industry towards continuous R&D and technology improvement. Increased product demand in manufacturing has pushed the "do more with less" attitude down the supply-chain to the machining industry.¹⁴
- **Shorter Production Lead-times** - The machining industry is expected to produce a larger quantity of product in less time.¹⁵ This also requires that machining businesses hold more raw materials on-site in case a high-priority order comes in which leads to having less cash on hand for other business expenses.
- **Higher Quality Control** – Machining suppliers are expected to produce larger quantities in less time, without defects, while always meeting the customer expectations.¹⁶

¹² Kline, S. (2013, December 1). American Manufacturing on the Rise. Modern Machine Shop. Retrieved June 11, 2015 from <http://www.mmsonline.com/articles/american-manufacturing-on-the-rise>

¹³ Finegold, D., Brendley, K.W., Lempert, R., Henry, D., Cannon, P., Boultonhouse, B., & Nelson, M. (1994). *The Decline of the U.S. Machine-Tool Industry and Prospects for Its Sustainable Recovery*. Washington D.C.: Rand

¹⁴ Makino. (n.d.) Cutting Tools and Market Trends in the USA. Retrieved June 11, 2015 from <http://www.makino.com/about/news/cutting-tools-and-market-trends-in-the-usa/175/>

¹⁵ Ibid.

¹⁶ Ibid.

- **Machine Tool Utilization** – Machining businesses are expected to maximize the capacity of their whole operation.¹⁷ Through systems like MTConnect,¹⁸ and others, businesses can see the peak performance of their machines and operators. Moreover, through machine tool utilization, businesses can know the optimum time to service a machine and conduct routine repairs in order to maximize productivity.

NATIONAL CONVERSATIONS

EXISTING ROADMAPS

The existing national technology roadmap for the machine tool industry was conducted in 2002 by the Association for Manufacturing Technology.¹⁹ This roadmap was an update of the 1996 technology roadmap performed by the same organization. The report identifies that machine tool producers must adapt and provide products that address the following properties:

- **Flexibility** – the capability of machine tools to address a wide range of different tools with minimum downtime for change.
- **Accuracy Capability**- the ability of a machine to accurately meet the specifications of the desired workpieces
- **Production Rate** – the number of workpieces that are produced over time (cycle time)
- **Delivery Cycle** – the amount of time from when the order is placed to the successful production
- **Reliability/Maintainability** – reliability is the ability to produce products without having a machine tool failure; maintainability is the ease of maintaining the machine.
- **Safety, Ergonomics, and Environmental Response Safety** –the assurance of safe conditions and meeting the physical demands while not exceeding the standards and regulations to which it has been assigned.
- **User Friendliness** – the ease of operation and maintainability of a machine tool

Beyond discussing what is needed in the machine tool itself, the report identifies what machining businesses need in order to maintain efficient businesses practices. The report identified four common needs and opportunities:

- **Reduction of Non-Value-Added Time** – non-value-added time is downtime spent on machines for parts change-over, machine waiting, or other machine waiting periods
- **First Part Correct** – debugging the machine after the first run of a part to correct for any defects in the run
- **Control-Related Approaches to Machine Improvements**- improve repeatability and maintain consistency to monitor, diagnose, and adjust for causes of inaccuracy.
- **Systems Approach to Machine Purchases** – suppliers must work within a systems approach where they must supply not only a machine tool, but also all other parts related to machining. Moreover, they must supply all of this within the quoted delivery schedule.

¹⁷ CNC Concepts. (2007). Two Articles on Machine Utilization and Costing. Retrieved on June 13, 2015 from <https://www.cncci.com/resources/tips/machine%20util%20and%20costing.htm>

¹⁸ <http://www.mtconnect.org>

¹⁹ Association for Manufacturing Technology. (2002). A Technology Roadmap for the Machine Tool Industry 2002 Edition. McLean, VA

NEW TECHNOLOGY IN MACHINING

New technology advancements in machining have made the industry more productive and competitive with offshore counterparts. These technologies allow machining companies to produce more product, but as mentioned earlier, customer demands require strict quality control while keeping the product on-time. The conversations below about machining innovations (multi-axes machines, micro-machining, and digitization and utilization) can be considered opportunities as well as challenges within the industry; opportunities, when realizing that such technologies can open the door for greater productivity, efficiency, and profit; and challenges, when understanding that it is hard for many machining businesses to adopt these technologies, as well as adjust their workforce the new technologies.

Multi-Axes Machines

- As the machining industry continues to look for methods of streamlining operations, technological advancements such as multi-axes machines have had a profound influence.²⁰
- Multi-axes machines can have either 3- or 5-axes. A 3-axes machine allows the drilling tool to approach the machined surface from three directions.²¹ A 5-axes machine allows for the drilling tool to approach the machined surface from the same three directions, but it also allows the machined surface to pivot in two directions while the machine tool is working.²²
- This machine allows manufacturers to consolidate and standardize their processes in a single machine. As a result, setup times are reduced and the machine can be tailored to suit a variety of different manufacturing operations such as turning and cutting.²³
- This machine has allowed manufacturers to achieve greater operations flexibility, quality control, and cost reduction.

Micro-Machining

- Micro-machining refers to techniques for fabrication of 3D structures on the micrometer scale. The design and construction of tools, tool holders, cutting tools, and electrodes need to evolve as greater demands are placed on the industry for machining these miniature parts. The most important micro-machining techniques are photolithography, laser, micro-EDM and micro-mechanical machining (micro-cutting and micro-milling).²⁴
- Micro-machining offers production efficiency and processing quality. This technology offers the benefit of producing components that are far more precise, intricate, and geometrically challenging, provides superior flexibility through adaptable set-ups and programmed automation, and offers cost avoidance with the elimination of molds, tools, and dies.²⁵
- The demand for micro-machined products is expected to increase; one reason for this potential increase is that a segment of this market is demand from medical device manufacturers who have seen an increase in demand from the aging U.S. population.²⁶

²⁰ Jaster, M. (1 June 2015). Lean Hobbing Gears on a Multi-Axis Machine. *Modern Machine Shop*.

²¹ Das, B. a. (2015). *Machining A Component Using Vision Based 3-Axis Cartesian Robot*. *International Journal of Applied Engineering Research*.

²² Korn, D. (Nov. 2013). A Smooth Transition to Five-Axis Machining. *Modern Machine Shop*.

²³ Jaster, M. (1 June 2015). Lean Hobbing Gears on a Multi-Axis Machine. *Modern Machine Shop*.

²⁴ Heidari, F. (2013). Micromachining: A New Trend in Manufacturing. American Society for Engineering Education.

²⁵ Media, A. B. (Nov.-Dec. 2011). Roundtable Q&A Machining - Interview with Igor Lukash (Technical Director, Gateway Laser Services) and Mike McCormick (Manager of Technology and Automation). *Medical Design Technology*.

²⁶ Morea, S. (2015, January). IBISWorld Industry Report 33271: Machine Shop Services in the US. *Ibis World*.

- For product designers and engineers, the relentless pace of innovation and ever-rising consumer expectations means that they must continually explore new manufacturing technologies and processes that improve flexibility, speed, and reliability, as well as lower costs and fast turnaround.²⁷

Digitization & Utilization

- One of the strongest technology trends in manufacturing today is the installation of robotic equipment. A new generation of robots is on the way—smarter, more mobile, more collaborative and more adaptable; designed to work in proximity to people.²⁸
- Technological advances have made robots:²⁹
 - More “aware” of their surroundings, allowing them to operate safely, and with more dexterity, near human workers on the production line.
 - Using sonar, cameras or other technologies, collaborative robots can sense where people are and slow down or stop to avoid hurting them.³⁰
 - More intuitive software interfaces has improved production efficiency.
 - Robotic equipment has also dropped dramatically in cost, making it more accessible and affordable.
 - Complex procedures that once required multiple machining operations can now be completed on a single machine, reducing operational costs and shortening lead times.

ENERGY EFFICIENCY & SUSTAINABILITY

Within the automotive, machining and molding industries, the topic of energy efficiency and sustainability is extremely important since energy and fuel costs can dip into profits. Recently, the cost of fuel has dropped, but as finite fuel resources are depleted, small and medium-sized manufacturers will always seek a balance between operating expenses and profitability.³¹

Energy Efficiency

- The most compelling trend relates to the staggering amount of power that drives each factory; 42% of the world's electricity is consumed by factories. Of that 42%, roughly two-thirds is used to drive the motors in factory machines.³²
- Manufacturers are presented with different types of energy-saving challenges because of unique and varied industry applications and facility layouts. For years, electricity costs have been viewed as a fixed cost in the operations world, with building management usually not in the discussion.³³ Additionally, operation managers did not have the resources to look at energy monitoring, and the cost of retrofitting a facility was simply too high in the short term.
- Due to technological advancements, there are an increasing number of methods for tracking and managing energy and resource consumption. Several of these methods include:

²⁷ Zhang, H. (12 May 2015). Laser Processing Enables Smaller, Faster Mobile Devices. *Industrial Laser Solutions*.

²⁸ Hagerty, J. R. (2 June 2015). Meet the New Generation of Robots for Manufacturing. *Wall Street Journal*.

²⁹ Crawford, M. (Winter 2014). Advanced Technology and the Changing Face of U.S. Manufacturing. Area Development.

³⁰ Hagerty, J. R. (2 June 2015). Meet the New Generation of Robots for Manufacturing. *Wall Street Journal*.

³¹ Society of the Plastics Industry. (2005). Improving Energy Efficiency at U.S. Plastics Manufacturing Plants. U.S. Department of Energy.

³² Maxey, K. (September 11, 2014). Current and Future Trends in Industrial Automation. Engineering.com.

³³ Gerke, G. (April 16, 2015). How Building Energy Management Can Help Your Factory. *Automation World*.

- Modern building automation systems and energy management systems allow facility managers to track energy consumption.³⁴
- Machine weight reduction and consolidation -- reducing the size of machines and designing machines that can perform multiple tasks has reduced energy consumption and the operation facility's physical footprint.³⁵
- Minimum quantity lubrication and near dry machining --lubricants are applied to cutting tools with a fine spray of oil exactly when and where it is needed, eliminating the need for large quantities of conventional metalworking fluids while providing the same amount of lubrication with much less environmental waste.³⁶

SUSTAINABILITY

“Sustainable manufacturing” has been defined as “the creation of manufactured products that use processes that are nonpolluting, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers, including the manufacturing of sustainable products and the sustainable manufacturing of all products” (p. 1085).³⁷ Sustainable machining has been precisely defined as “the manufacture of products (components, etc.) by a subtractive process based on cutting (material removal by the cutting action of a tool usually with a machine tool to create surfaces and features) in a way that is nonpolluting, minimizes and conserves energy and natural resources, and is economically sound and safe for employees, communities, and consumers” (p. 1085).³⁸

NEW MATERIALS

- New materials have been considered a “game changer” across the spectrum of manufacturing.³⁹ New materials consist of a variety of mediums such as ceramics,⁴⁰ alloys (high-temperature, nickel-based, iron and cobalt-based) and stainless steels.⁴¹ Although many of these new materials are difficult to work with, there is a large consumer demand to use them.
- Industry segments that are pushing for the use of these new materials are automotive, defense and aerospace markets. Technology development in machining is largely driven by these industries.⁴²
- Laser assisted machining (LAM) is emerging as a viable industrial option for the machining of difficult-to-machine materials. LAM works by heating localized portions of workpieces, assists in the cutting of ceramics, and has also been successfully applied to milling.⁴³
- Outside of new materials there is a segment called “exotic” materials. These materials “display excellent wear characteristics, durability and service life in high heat, extreme cold or corrosive

³⁴ Gerke, G. (April 16, 2015). How Building Energy Management Can Help Your Factory. *Automation World*.

³⁵ UNIDO. (2013). Greenshoots: Manufacturing turning a new leaf. Network 18 Publishing.

³⁶ EHSToday. (November 2013). Near-Dry Machining Helps Ford Cut Water and Oil Use. Penton Media, Inc.

³⁷ Dornfeld. (2014). *CIRP Encyclopedia of Production Engineering*. Springer International Publishing AG. Retrieved on June 20, 2015 from http://link.springer.com/referenceworkentry/10.1007%2F978-3-642-20617-7_6702.

³⁸ Ibid.

³⁹ Morea, S. (2015, January). IBISWorld Industry Report 33271: Machine Shop Services in the US. *Ibis World*.

⁴⁰ Srejith, P.S. & Ngoi, B.K.A (2001) Material removal mechanisms in precision machining of new materials. *International Journal of Machine Tools and Manufacture*, 41 (12), 1831-1843.

⁴¹ National Technical Conference Indianapolis. *Difficult to Machine Materials*. <https://www.pmpa.org/docs/default-source/technical-conference/difficult-to-machine-materials-intro.pdf?sfvrsn=0>

⁴² Morea, S. (2015, January). IBISWorld Industry Report 33271: Machine Shop Services in the US. *Ibis World*.

⁴³ Shin, Y. (2011, January/February) Laser Assisted Machining. *Industrial Laser Solutions*. 18-22

environments.”⁴⁴ (p. 36) Exotic metals include titanium, Kovar, Invar and Monel; exotic non-metals include glass-filled plastics, Kevlar, machinable glass and machinable carbide.

- In the past, many machine shops would not consider taking a job using exotic materials because there was a lack of knowledge about these materials; today, because of information on the Internet, listservs and blogs, machine shops will tackle jobs they would never have considered previously.⁴⁵

WORKFORCE

More than ever, there is a need for middle-skill employees. The Harvard Business Review states, “Shortages of workers for these types of jobs [middle-skilled] are already undermining U.S. competitiveness and causing firms to shift their operations abroad.” (p.83).⁴⁶ In order for the United States to have a sustainable workforce, it must address the pipeline issue of middle-skilled jobs. According to both the Manufacturing Institute and Deloitte, the skills gap in U.S. manufacturing is getting wider with nearly 3.5 million manufacturing jobs that will likely need to be filled and a skills gap that is expected to result in 2 million of those jobs going unfilled.⁴⁷ Deloitte points to two contributing factors to this skills gap: baby boomer retirements and economic expansion.

In order to help understand the factors that contribute to the skills gap, the Government Accountability Office (GAO) audited the Department of Labor’s (DOL) Workforce Investment Act (WIA) Adult Dislocated Worker program and most local areas had a hard time filling middle-skill occupations because individuals lacked sufficient skills to participate even in the training programs.⁴⁸ The GAO report showed that this problem has two distinct aspects: not only do individuals lack the cognitive skills required to enter middle-skill jobs, but also, managerial practice was rewarding quick employment placement rather than skill improvement means that employers are challenged to fill these middle-skilled, high-demand occupations.

ROLE OF INDUSTRY PARTNERS

Of all the players in the machining and machine tooling industry, the private sector has played a dominant role in all aspects. However, the private sector does rely on industry partners such as universities and the government in public-private partnerships for all types of initiatives (R&D, workforce development, etc.) that could not be tackled in the private sector.

Entrepreneurs

It is interesting to note that entrepreneurs are seeing manufacturing as a new market segment due to its changing nature and lower cost of entry. Manufacturing is now becoming an industry where entrepreneurs feel comfortable to enter because of low cost tools, web resources, and crowd funding resources.⁴⁹

⁴⁴ Gentile, J. V. (2012, October) Considerations for Machining Exotics. *Production Machining*. 36-40.

⁴⁵ Ibid.

⁴⁶ Kochan, T., Finegold, D., & Osterman, P. (2012, December). Who Can Fix the "Middle-Skills" Gap? *Harvard Business Review*, pp. 83-90.

⁴⁷ Giffi, C., et. al. (2015). The skills gap in U.S. manufacturing 2015 and beyond. Deloitte Consulting.

⁴⁸ Government Accountability Office. (2013). *Workforce Investment Act: Local Areas Face Challenges Helping Employers Fill Some Types of Skilled Jobs*. Washington, D.C.: U.S. Government.

⁴⁹ Muro, M. (3, June 2015) Why a Manufacturing Startup Is Doable. *Wall Street Journal*. Retrieved June 11, 2015 from <http://blogs.wsj.com/experts/2015/06/03/why-a-manufacturing-startup-is-doable/>

Academia

Academia plays a role in the machining conversation through involvement in workforce development, providing technical assistance, and assisting in commercialization efforts. Some activities that universities are involved in include:

- **Workforce Training/Skills Development:** Increased use of technology in the manufacturing sector has led to a greater need for skilled labor. Universities and community colleges have begun to design programs that prepare the workforce by emphasizing courses such as digital design, rapid prototyping, production, computer-aided machining, 21st century manufacturing strategy and technology commercialization, and advanced business skills.⁵⁰
- **Process and product improvement:** Universities have begun to help advanced manufacturing companies find solutions, train employees, improve their processes and products, and adopt and deploy advanced manufacturing technologies.⁵¹
- **Incubation/Commercialization/Tech Transfer:** Many universities have established space on campus for students to prototype ideas and collaborate on technology ventures that can lead to new startup companies.⁵²
- **Business Mentorship and Access to Capital:** Many universities connect students with successful alumni entrepreneurs and national entrepreneurship organizations that provide mentorship, and sometimes financing, to the student-led startups. The goal of mentorship and the access to capital is that students will be more successful in their bids to start companies.⁵³

Government

The public sector has an inherent interest in advancing the machining industry. Scientific progress is thought to be a public good in that it often leads to greater quality of life, health, first rate universities and a robust economy supporting more jobs and tax revenues. The government's role in basic research can be justified by these social benefits. In this way, the government often takes the biggest risks. Private companies are unlikely to invest in such risky projects, which at best offer a long shot at financial rewards many years down the road.⁵⁴ There are three ways in which the government plays a role in advancing the machining industry:

- **Workforce Development:** Across the United States, both the federal and state governments have invested heavily in training programs, typically partnering with local community colleges and universities, to address skills gaps within the machining industry.^{55,56,57,58,59}
- **Research and Development:** Throughout history the federal government has provided financing for research and development focused on technological advancement.^{60,61} In addition to providing financing to research institutions, the government has also begun to invest in business

⁵⁰ Norris, H. (June 2, 2015). CCBC adds new degree program in advanced manufacturing. *Catonsville Times*.

⁵¹ Tilton, R. (May/June 2015). Industry Focus: Advanced Manufacturing – Manufacturing High-Tech Growth. *Business Facilities*.

⁵² Fell, A. (October 4, 2013). New center to help entrepreneurial student engineers. U.C. Davis.

⁵³ Ibid

⁵⁴ Porter, E. (May 26, 2015). Government R&D, Private Profits and the American Taxpayer. *New York Times*.

⁵⁵ Michelle Griffin Young: Industry partnerships a winning combination for Pennsylvania. (June 15, 2015). *The Morning Call*.

⁵⁶ Anglebrandt, G. (May 28, 2015). Is STEM taking root? *Crain's Detroit Business*.

⁵⁷ Moretto, M. (May 28, 2015). Maine House speaker's \$5 million job training bill gets green light from labor committee. *BDN Maine*.

⁵⁸ Maitre, M. (May 27, 2015). State names winners of multi-million dollar career education grants. *EdSource*.

⁵⁹ Students Complete Training in Basics of Machining. (May 19, 2015). *Gant Daily*.

⁶⁰ Wenzl, R. (October 3, 2014). \$1.9 million grant will help Wichita State build unprecedented high-tech lab. *The Wichita Eagle*.

⁶¹ Kodak Partners with National Innovation Accelerator to Push Technology Forward. (April 13, 2015). *Agence France-Presse*.

incubators, or “maker spaces”. These spaces provide cash strapped entrepreneurs with the advanced machining equipment to create prototypes and models.⁶²

- **Purchasing goods and services:** The federal government contracts with small, medium, and large machining enterprises throughout the county for goods and services.⁶³

INTERNATIONAL CONVERSATIONS AND TRENDS

In a global manufacturing arena, increasing productivity is directly related to competitiveness. Cutting-edge machining technology, more efficient machine tools and higher skilled workers make the most of these advanced technologies and are the components of higher productivity.⁶⁴ Major producers and consumers of machine tools and technologies contribute the most to international conversations in the topic area. Currently, the top consumer country of machine tools is China, followed by the United States, Germany, South Korea and Japan. In terms of machine tool production, China ranks first, followed by Germany (2nd), Japan (3rd), South Korea (4th) and Brazil (5th).⁶⁵ This section focuses on major global conversations and trends in machining technology and machine tools.

Europe

CECIMO, the European Association of the Machine Tool Industries, examined the competitiveness of the European machine tool industry in 2011.⁶⁶ They conducted a SWOT (strengths, weaknesses, opportunities, and threats) analysis to examine the strategic outlook for industry in Europe.

Strengths

- Technology & Innovation - High-end technology, innovation capacity, and public R&D resources
- Human Capital Resources - Highly skilled labor, accumulated engineering experience, vocational training, and multilingualism
- Supply-Chain integration - The existence of excellent downstream suppliers in Europe, and customer relationships

Weaknesses

- Regulatory EU hurdles - Administrative burdens, restrictions, tight regulations
- Globalization - Small enterprise dimension to attack global market, difficult access to Asian markets, adapting products to Chinese markets, and marketing
- Labor market pressures - Not sufficient supply of labor, image/priority amongst young people
- Machine tool internal business pressures - Limited access to financing (total risk on owner of small and medium sized manufacturers) and small size of average suppliers

⁶² FACT SHEET: New Commitments in Support of the President’s Nation of Makers Initiative. (June 12, 2015). The White House - Office of the Press Secretary.

⁶³ Gates, D. (May 30, 2015). Local space entrepreneurs take on the new frontier. *The Seattle Times*.

⁶⁴ World machine tool output and consumption survey. (2015). Gardner Business Media, Inc. Retrieved June 15, 2015 from <http://www.gardnerweb.com/cdn/cms/GR-2015-WMTS.pdf>

⁶⁵ Ibid.

⁶⁶CECIMO (2011, December) CECIMO Study on the Competitiveness of the European Machine Tool Industry. Retrieved June 4, 2015 from http://www.cecimo.eu/site/fileadmin/Publications/Studies_and_Reports/Study_on_Competitiveness_of_the_European_Machine_Tool_Industry_-_December_2011.pdf

Opportunities

- Globalization - Rising demand in China, EU enlargement, global economy growth, free trade agreements
- Customer Satisfaction - Develop customer services; customers do not have their own employees to develop production solutions), strong European image/brand
- Automation to make machining more cost effective and productive

Threats

- Globalization - Chinese competition, and moving European manufacturing to Asia
- Technology & Innovation - Access to materials and intellectual property infringements
- Labor market pressures - Limited interest of students in engineering, aging population, early retirement

Based on the analysis, two major sets of recommendations were developed by the European Association of the Machine Tool Industries:

1. Recommendations for the Industry

Several recommendations were made to help European manufacturers succeed in the global market. These were:⁶⁷

- 1) Protect intellectual property;
- 2) Develop new technologies through innovation;
- 3) Form alliances and expand cooperatively into other markets;
- 4) Rethink business organization and model to adapt to international markets;
- 5) Invest and expand in the Asian market;
- 6) Promote 'EU Brand';
- 7) Increase presence in China;
- 8) Produce affordable goods for growing markets; and
- 9) Invest in vocational training.

2. Recommendations for European Policymakers and National Governments

Recommendations were also made to provide direction for European policymakers and national governments. These were:⁶⁸

- 1) Concentrate on industry-driven innovation;
- 2) Modernize the European industrial base;
- 3) Foster innovation through the value chain;
- 4) Ensure a favorable business in Europe and adequate access to finance;
- 5) Remove trade barriers;
- 6) Provide support for SMEs and improve their market access;
- 7) Protect intellectual property;
- 8) Increase R&D funding;
- 9) Invest in vocational training;
- 10) Promote smart regulation in energy efficiency; and
- 11) International market surveillance.

⁶⁷CECIMO (2011, December) CECIMO Study on the Competitiveness of the European Machine Tool Industry. Retrieved June 4, 2015 from http://www.cecimo.eu/site/fileadmin/Publications/Studies_and_Reports/Study_on_Competitiveness_of_the_European_Machine_Tool_Industry_-_December_2011.pdf

⁶⁸ Ibid.

Asia

Not surprisingly, major Asian producers and consumers of machine tools have paid attention to machining technology and machine tools as a part of their science and technology strategic roadmaps

- **Japan** - The U.S. Commerce Department International Trade Administration examined Japan's Manufacturing Competitiveness Strategy.⁶⁹ Major components of this strategy included:
 - Identifying different levels of funding for various sectors based on initial R&D activities.
 - Building a lasting and progressive industry–academia–government collaboration.
 - Indorsing usage of new technologies in the public sector.
 - Encouraging entrepreneurial activities and R&D ventures by private enterprises.
 - Undertaking workforce development efforts.
- **China** - Realizing the importance of advanced manufacturing, including advances machining, China also has developed a science and technology roadmap to 2050.⁷⁰
 - The roadmap is divided into two parts: 1) intelligent manufacturing systems based on ubiquitous information and 2) environmental friendly green manufacturing.
 - The roadmap has focused on equipment with intelligent systems, which is related to the hardware of manufacturing automation and includes machine tools and machining centers.

Canada

The Canadian machining industry has outlined strategic goals in order to increase operational efficiency and global competitiveness within the sector. Trends have been divided into four major groups:⁷¹

1. **Sustainable manufacturing:** focused around high efficiency and near-to-zero emissions in the manufacturing process; alternatives to energy intensive manufacturing based on advanced production systems; improved use of renewable resources at the factory level; and production using environment-neutral materials.
2. **Information and computing technologies:** focused on the integration of the manufacturing supply-chain with marketing, operations, and new product development. Methods for achieving this include cloud computing to support corporate Enterprise Resource Planning (ERP) systems, a machine-to-machine concept that allows manufacturing equipment to communicate with ERP systems and with equipment manufacturers for service operations, and the idea of mobile computing as a platform for both production management and corporate communications.
3. **High performance manufacturing:** includes flexible adaptive production equipment, systems and plants for rapid (re)configurations and optimal energy use; high precision micro-manufacturing machines and systems; tools for production planning and “in-situ simulation”⁷² for open reconfigurable and adaptive manufacturing systems; and zero-defect manufacturing.
4. **New materials:** includes net-shape manufacturing for advanced structural and functional materials; new material functionalities through manufactured processes; manufacturing strategies for renovation and repair; and product design using sustainable material processing technologies.

⁶⁹ Corwin, J. & Puckett, R. (2009). Japan's Manufacturing Competitiveness Strategy: Challenges for Japan, Opportunities for the United States. United States Department of Commerce.

⁷⁰ Wang, T. (2010). Advanced Manufacturing Technology in China: A Roadmap to 2050. Science Press Beijing.

⁷¹ Doern, F. (2012). An Assessment of Technology Roadmaps for Advanced Manufacturing. Red River College. Retrieved June 13, 2015 from <http://blogs.rrc.ca/ar/wp-content/uploads/2014/06/DTAPP-and-Technology-Roadmaps-.pdf>.

⁷² In-situ simulation is simulation that takes place in the actual working environment and involving those who work there as opposed to center-based simulation that occurs in a separate simulation center.

This roadmap also conducted surveys of small and medium enterprises throughout Manitoba, Canada, to identify their technology priorities. The Canadian machining industry found that there were four major areas:

1. The use of automation and robots to enhance quality, safety, and productivity.
2. The integration of information and computing technologies to improve production and supply chain activities.
3. The adoption of advanced manufacturing technologies and new materials to promote new process and product improvements.
4. The adoption of advanced product life cycle management software to provide for a virtual factory simulation.

STATE CONVERSATION

Several states across the United States have emphasized the importance of machining in advanced manufacturing processes. A series of actions have been taken by the states to enhance productivity and facilitate growth of manufacturing through advanced machining technologies. Efforts undertaken by the states across the United States can be summarized into four major themes:

IMPROVE THE ECONOMIC HEALTH OF STATES THROUGH INNOVATION IN MACHINING TECHNOLOGY

Innovation in machining technology can provide pathways for the states to manufacture products competitively. Innovation can result in different types of outcomes—ranging from new products to efficiency gains to optimization of manufacturing plants and supply networks. In machining, similar to other advanced manufacturing processes, a particular focus has been paid to the integration of non-conventional technologies, such as lasers, to develop new multifunctional machining processes.⁷³

Generally speaking, states have aimed at fostering a favorable environment for innovation in machining technology as well as for formation, retention and expansion of advanced technology-related enterprises. Realizing the importance of small and medium-sized enterprises (SMEs) for the economic health of the state, some states have also paid specific attention to these SMEs and the need for technology transfers to help them grow. Massachusetts has employed several programs to foster innovation in different areas of advanced manufacturing technologies. For example, Massachusetts Technology Transfer Center (MTTC) aims at enhancing the commercialization process by implementing programs to increase the quantity and quality of new technologies transferred, educating scholars on entrepreneurship and the technology commercialization processes, and building a collaboration between researchers, company executives, and professional financiers to share information about recent technological advances and their potential uses.⁷⁴

INVEST IN WORKFORCE DEVELOPMENT PROGRAMS

State governments undertake workforce development efforts to prepare their residents for the jobs of today and tomorrow as well as to help industries grow. Whereas workforce development initiatives vary across the country, they usually aim at promoting economic development, education, and training

⁷³ Doern. (2014). An assessment of technology roadmaps for advanced manufacturing. Red River College. Retrieved June 13, 2015 from <http://blogs.rrc.ca/ar/wp-content/uploads/2014/06/DTAPP-and-Technology-Roadmaps-.pdf>.

⁷⁴ Government Sponsored Innovation Programs. (2014). Retrieved June 20, 2015 from <http://www.northeastern.edu/governmentrelations/research/innovation/>

through partnerships with businesses.⁷⁵ Several states have specific workforce development programs tailored to the needs of certain advanced manufacturing processes, such as machining. One prominent example is Illinois' Accelerated Training for Illinois Manufacturing,⁷⁶ which helps individuals gain skills in one of four high-demand areas in manufacturing: 1) machining; 2) mechatronics (i.e. equipment service and repair); 3) welding; and 4) logistics/inventory. Participants of the program take advantage of personal career development; paid job skill training and national credential exams; work-based learning opportunities with employers; ongoing team counseling; and ultimately permanent job placement.⁷⁷

Local chapters of the National Tooling and Machining Association (NTMA) offer several apprenticeship training programs as well as programs to re-educate business owners in order to foster growth in machining technologies. For instance, Rock River Valley Tooling and Machining Association is in Rockford, Illinois that offers apprenticeships, scholarships, and several other benefits for its members.⁷⁸

Technical, trade and career schools, community colleges and universities across the country also offer programs to train semi-skilled and skilled workers in the high-demand area of machining. For instance, Capital Area Career Center, located in Mason, Michigan, offers a precision machining technology course open to high school juniors and seniors in certain school districts.⁷⁹ Another example is the Machine Technology Program offered by colleges in Kansas preparing individuals to apply technical knowledge and skills to various dimensions of machining processes.⁸⁰

ENHANCE SAFETY AND CONFIDENCE IN MACHINING PROCESSES AND PRODUCTS

Improving safety in machining processes and products is another area to which states have paid considerable attention. Ensuring that products and processes are safe and reliable may require “tracking of sustainable production and real-time handling of materials” (p. 28).⁸¹ Integration of automation and industrial robotics solutions can often enhance safety while improving quality and productivity simultaneously. Whereas many states support the development of technologies that can potentially enhance safety, some states have also developed numerous safety programs and plans. For example, Washington State Department of Labor and Industries offers several safety programs, plans, and informational and advisory materials to enhance safety.⁸²

⁷⁵ Federal and state initiatives. (n.d.). AFPM Workforce Development. Retrieved June 16, 2015 from <http://workforce.afpm.org/Career-Resources/federal-and-state-initiatives.html>

⁷⁶ Accelerated training for Illinois manufacturing. (2013). Illinois Department of Commerce and Economic Opportunity. Retrieved June 18, 2015 from <http://www.ilworknetmanufacturing.com/ATIM/Pages/default.aspx>

⁷⁷ Federal and state initiatives. (n.d.). AFPM Workforce Development. Retrieved June 16, 2015 from <http://workforce.afpm.org/Career-Resources/federal-and-state-initiatives.html>

⁷⁸ Leading the way to precision manufacturing. (2015). Rock River Valley Tooling & Machining Association. Retrieved June 18, 2015 from <http://www.rrvtma.com/>

⁷⁹ Precision machining technology engineering/manufacturing and industrial technology. (2015). Ingham ISD. Retrieved June 13, 2015 from <http://www.inghamisd.org/cacc/futurestudents/programsbypathways/engineeringmanufacturingindustrialtechnology/precisionmachining/>

⁸⁰ Machine technology. (n.d.). Kansas Board of Regents. Retrieved June 13, 2015 from http://www.kansasregents.org/workforce_development/program_alignment/machine_technology

⁸¹ Doern. (2014). An assessment of technology roadmaps for advanced manufacturing. Red River College. Retrieved June 13, 2015 from <http://blogs.rrc.ca/ar/wp-content/uploads/2014/06/DTAPP-and-Technology-Roadmaps-.pdf>

⁸² Sample safety programs and plans. (n.d.). Washington State Department of Labor & Industries. Retrieved June 13, 2015 from <http://www.lni.wa.gov/Safety/TrainingPrevention/Programs/?F=M>

PROMOTE SUSTAINABLE BUSINESS PRACTICES

Sustainability is one of the repeated themes in state discussions about advanced manufacturing and machining. The emphasis on sustainability may take different forms, ranging from “smart”⁸³ products and processes,⁸⁴ to energy efficiency and use of alternative energy sources. Because manufacturing is a component of “the supply chains for health care, business services, national defense, energy, construction, and environmental sustainability” (p.10),⁸⁵ specific attention has been paid to processes, products, and materials that minimize environmental impacts. State-level efforts in this area have typically taken the form of fostering innovation in sustainable machining processes and products.

TAKEAWAYS & POLICY IMPLICATIONS

- ✓ **Address long-standing needs of the industry.** The machining and machine tool industry is still struggling with the same issues of 30 years ago during the decline in the 1980s:
 - Many people point to the workforce as any easy scapegoat when identifying the needs of the industry, but there are many unaddressed needs that should be tackled.
 - In 1994, Fiengold, et. al., identified three recommendations to improve the machine tool industry and help it rebound from the decline of the 1980s. Of the three recommendations, the industry is still struggling with two of them today: improving technology adoption and increasing overall investment in the manufacturing infrastructure (i.e. basic research, transferable skills). The third recommendation was a modification of U.S. trade policy away from domestic protection towards free trade, has mostly taken place.
 - The 2002 roadmap by the Association for Manufacturing Technology identified four of the industry’s needs and opportunities, all of which the industry struggles with today: 1) reduction of non-value-added time, 2) “first part correct”, 3) control-related approaches to machine improvements, and 4) use of a systems approach to machine purchases.

- ✓ **Advanced materials are a larger issue for the entire advanced manufacturing community**, not just for the machining and machine tool industry. Therefore, it is recommended that the advanced manufacturing community, in consort with the machining industry, tackle the issue of advanced materials. Other industry struggles include:
 - Additive manufacturing (AM) struggles with advanced materials because this industry is trying to understand the fundamentals of materials, processes, and applications.⁸⁶ To better understand and use advanced materials in AM processes, it is suggested that research be conducted to understand the physics and chemistry of AM processes, develop processes based on scalable material methods, and investigate why some materials can be used in AM and others cannot.⁸⁷

⁸³ Smart products and/or processes are often characterized by less waste and energy use, increased efficiency, fast turnaround and better quality.

⁸⁴ Doern. (2014). An assessment of technology roadmaps for advanced manufacturing. Red River College. Retrieved June 13, 2015 from <http://blogs.rrc.ca/ar/wp-content/uploads/2014/06/DTAPP-and-Technology-Roadmaps-.pdf>

⁸⁵ Making our future: What states are doing to encourage growth in manufacturing through innovation, entrepreneurship, and investment. (2013). National Governors Association. Retrieved June 13, 2015 from <http://www.coecon.com/assets/ngamanufacturing.pdf>.

⁸⁶ Bourell, D.L., Beaman, J.J., Leu, M.C., & Rosen, D.W. (2009). A Brief History of Additive Manufacturing and the 2009 Roadmap for Additive Manufacturing: Looking Back and Looking Ahead. US-Turkey Workshop On Rapid Technologies, September 24 – 24, 2009

⁸⁷ Guo, N. & Leu, M.C. (2013). Additive manufacturing: technology, applications and research needs. *Frontiers in Mechanical Engineering*. 8(3), 215-243

- In the molding industry, the American Chemistry Council's technology roadmap that sets forth a strategy for the industry through 2030 considers improving and fostering new materials as a component of their roadmap.⁸⁸

The development and reinforcement of cross-sector collaborations is critical to the long-term success of the machining industry.^{89,90} Cross-sector collaborations establish a platform for consistent communication between the private, public, and academic sectors. It is through these cross-sector collaborations that all sectors can voice their concerns and display their talents.

- The private sector manufacturers are able to voice their concerns regarding technology and workforce needs.
- Academics and researchers have an opportunity to demonstrate their current work, receive input and direction from practitioners, and allow for effective technology demonstration and validation activities.
- Government is able to keep their thumb on the pulse of current and emerging technological trends within the industry, allowing them to facilitate growth more effectively.

⁸⁸ (2014, March). *Plastics and Polymer Composites for Automotive Markets Technology Roadmap*. American Chemistry Council.

⁸⁹ Doern, F. (2012). *An Assessment of Technology Roadmaps for Advanced Manufacturing*. Red River College. Retrieved June 13, 2015 from <http://blogs.rrc.ca/ar/wp-content/uploads/2014/06/DTAPP-and-Technology-Roadmaps-.pdf>.

⁹⁰ Porter, E. (May 26, 2015). *Government R&D, Private Profits and the American Taxpayer*. *New York Times*.