Discussion White Paper on Multi-Disciplinary Research Opportunities at Wayne State University: Advancing Manufacturing Systems & Digital Design

Overview: Next Generation Manufacturing

Rapid advances in cloud-based computing, robotics and smart sensors, multimodal modeling and simulation, and advanced production are transforming modern manufacturing. As a recent paper from the National Academy of Engineering's *Symposium on the Frontiers of Engineering* explains, there is a significant change underway in manufacturing that will define how the next generation of manufacturing innovation and execution are advanced.

> "Challenging economic trends, rising value chain complexities, and intensified global competition are driving the manufacturing industry to upgrade its execution systems. And advances in cloud computing, big data, social collaboration technologies, and mobility are prompting society in general toward the digitally connected enterprise and value chain, which must ultimately satisfy the demands of a better-educated and socially aware consumer... For manufacturers, the challenges are encouraging a fundamental reassessment of their current and future factories."[1]

Increasingly a systems approach to manufacturability is being required for advanced manufacturing that involves seamlessly connecting computer design tools, modeling and simulation, intelligent machines and sensors, additive and subtractive manufacturing methods, and advanced supply chain and distribution management for reducing the time for product development, the costs in manufacturing processing, assembly, and distribution, and the need for component testing.

From Battelle's recent interviews with leading manufacturers[2] in the U.S., the inter-related efforts needed for advanced manufacturing include:

- Advancing a systems approach to manufacturability to improve overall enterprise systems using advanced sensors and instrumentation for real time data to decisions as well as computer modeling and simulation to improve manufacturing operations.
- Advancing industrial robotics and reaching the next level of manufacturing automation:

[1] Christian Will, *Dassault Systèmes*, "Business Process Management Systems to Optimize Manufacturing," Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2013 Symposium, National Academy of Engineering, 45-54

[2] Includes recent interviews with senior executives at Cummins Engine, General Electric, Stanley Black & Decker, General Dynamics and United Technologies Corporation.

  - Wide uses of robotics in manufacturing sought—both for continuous assembly manufacturing as well as specialized high value, low quantity components
  - Interest in robotics for tooling and inspections.
- Improved human-machine systems operation and interfaces, such as augmented reality to help operator with tasks and advancing embedded systems
- Digital manufacturing design innovation to go to market quicker with new products and aid in design and testing of products.

This growing competency in advancing key components, systems and processes used in advanced manufacturing combined with advanced mobile computing networking and smart sensor systems offers a strong alignment with the direction of advanced manufacturing research and development by the federal government and industry.

While the federal government has been an important source of funding for advanced manufacturing to both industry and universities, there has been a renewed focus with the commitment by the Obama Administration to advancing a National Network for Manufacturing Innovation program. The NNMI is focused on filling the gap in the innovation infrastructure, allowing new manufacturing processes and technologies to progress more smoothly from basic research to implementation in manufacturing. Its approach is to create a robust national innovation ecosystem anchored by up to fifteen Institutes for Manufacturing Innovation (IMI), each with a unique technology focus. In an IMI, industry, academia and government partners collaborate and co-invest to nurture manufacturing innovation and accelerate commercialization. To date, four IMIs have been identified involving the technology areas of additive manufacturing, power electronics, digital manufacturing and design, and lightweight and modern metals manufacturing. Other announced center competitions have been identified in clean energy-related composites materials and structures, biomanufacturing and, most recently, integrated photonics.

Along with this renewed focus on advanced manufacturing by the federal government is the increasing importance of having an industry facing research program to be competitive for federal research funding in advanced manufacturing. The need for an industry facing research program in advanced manufacturing is not only critical in helping to define the focus of university-related research activities, but in demonstrating the capability to translate university research activities to industry partners for applied research and development and commercialization.

The efforts by the federal government through the NNMI is a component of a larger change taking place in federal research funding for advanced manufacturing. Concomitant with a significant increase in federal government investment in the development of advanced manufacturing processes and products, with the administration's FY 2015 budget (currently operating on a Continuing Resolution) providing $2.2 billion for advanced manufacturing R&D an increase of 14% from FY 2014 and substantially higher than the $1.5 billion of federal R&D support for advanced manufacturing in FY 2011.[3] These federal investments will be made across primarily NSF, DOE, DoD, and NIST.

This increased level of federal R&D for advanced manufacturing also is heralding an increased focus on industry engagement in demonstrating the value of the research and how it is to be translated into advanced manufacturing products and processes. As the National Science and Technology Council sets

[3] FY 2015 based on Battelle analysis of continuing resolution and FY 2011 estimate from National Science and Technology Council, A National Strategic Plan for Advanced Manufacturing, February 2012, page 27.

out in its 2012 National Strategic Plan for Advanced Manufacturing that is guiding not only the establishment of the NNMI but overall increased federal spending for advanced manufacturing:

> "The acceleration of innovation for advanced manufacturing requires bridging a number of gaps in the present U.S. innovation system. Academic researchers working on problems of importance to advanced manufacturing must communicate more effectively with their counterparts in industry. Federal investments in advanced manufacturing technologies and capabilities must align more fully with similar investments by states and regions and by the private sector."[4]

The NCST advanced manufacturing strategy is putting in place a portfolio approach to overseeing federal research spending on advanced manufacturing, focusing on four key areas of development: Advanced Materials; Production Technology Platforms; Advanced Manufacturing Processes; and Data and Design Infrastructure. In this emerging national approached to R&D for advanced manufacturing, the Federal government will continue to make investments in high-risk basic research by universities, but increasingly with an eye on how these promising, nascent technologies are positioned for broad industry adoption and commercialization as well as how they meet essential national security needs, which again requires close collaboration with defense industry contractors and their supply chain.

Wayne State University's Research Opportunities and Current Position in Advanced Manufacturing Research and Opportunities

Engineering and computer science research at Wayne State University has been on the rise. From 2007 to 2012, engineering grew by 22% reaching $20.3 million, compared to growth in total research expenditures of just 3%. Computer sciences, which is part of the College of Engineering at Wayne State University, has also been growing rapidly, growing by over 60% from 2007 to 2012, and now stands at $3.6 million.

Looking forward, the College of Engineering in its 2012-2017 Strategic Plan has set ambitious goals of increasing its extramural funding by 50%, moving into the top 100 ranked engineering Colleges in research expenditures, and establishing a federal/industrial-funded center of excellence.

One area of excellence for Wayne State University's College of Engineering is in a multi-disciplinary approach to biomedical engineering, with particular strengths in imaging, diagnostics, bioinformatics, health care systems engineering and biomaterials. This area is discussed more fully in another strategic opportunity write-up.

Another growing area of capability found at Wayne State University is in advancing key components, systems and processes used in manufacturing. A close examination of Wayne State University's advanced manufacturing-related research suggests it is cross-cutting within the College of Engineering, led by the departments of Mechanical Engineering and Industrial and Systems Engineering, with other departments offering specific areas of research capabilities.

[4] IBID, page 19

Mechanical Engineering has been one of the fastest growing research areas at Wayne State University and is the largest area of funded research in engineering within the University. Research expenditures in mechanical engineering grew by 32% 2007-2012 and comprise 28% of total engineering research at Wayne State University. In mechanical engineering, Wayne State stands out through a number of its research centers. One is the Center for Automotive Research. Its research is focused on combustion, performance, fuel economy, emission controls, friction and wear, and simulation of automotive engines, alternate and renewable fuels, and biofuels. The Center is also an active member of a larger Army center of excellence for modeling and simulation of ground vehicles, where Wayne State brings expertise involving internal combustion engine and fuel studies, including the simulation and control of combustion and accurate predictive tools needed for the design and improvement of practical combustion systems. Another promising advanced manufacturing-related center within the Department of Mechanical Engineering is the Advanced Composites Research Laboratory, which offers a specialized lab for the fabrication of polymer composites, analytical modeling and mechanical testing of a wide variety of composites. It is known for its analysis of vibration responses in composite components, materials and structures as well as the design and manufacturing of composite components and materials for noise and vibration control. It also analyzes fracture and fatigue of composites under harsh conditions. Still, this is a relatively small research center that needs to be augmented if it is to have significant reach. Other individual faculty research is also found in areas related to combustion and energy conversion, fuel cells, disc brake dynamics and other topics in advanced manufacturing.

In Industrial and Systems Engineering, Wayne State University is a member of the Center for e-Design, an NSF-funded Industry/University Cooperative Research Center. The focus of this Center is to create and develop new design paradigms and electronic design tools that will assist in generating high quality products and systems at reduced cost and time. Wayne State University maintains a Computational Intelligence and Design Informatics Lab to focus on design informatics and design science. The industry members of this Center tend to be either heavy machinery, aerospace or engine manufacturers, such as Deere & Company, Caterpillar, Boeing, Lockheed Martin, Pratt & Whitney, or component/software companies to these manufacturers such as Cisco Systems, Siemens PLM Software and Moog Inc. No automobile manufacturers are members.

Another area of expertise at Wayne State University's Industrial and Systems Engineering Department is in supply chain management. This includes development and optimization models and methodologies for logistics systems in manufacturing and addressing issues in the sustainability of logistics operations and their interface with product design decisions. Among the sectors of focus are the health care and automotive industries. A recent planning grant was awarded to Wayne State University to become a member of the Center for Excellence in Logistics and Distribution (CELDi) that is currently led by the University of Arkansas. Other leading faculty members in Industrial and Systems Engineering also bring strengths in lean product development, engineering design methodologies, and statistical methods in quality and reliability engineering. In 2014, Wayne State University was awarded an NSF Grant Opportunities for Academic Liaison with Industry (GOALI) award to use structural information of system components to improve prediction of reliability and failure in complex systems,

with a focus on the auto industry. In particular, these models will be developed and applied to the autobody manufacturing system of ultra-high strength steels, which is currently of great interest to the automotive industry but faces challenges in failure prediction, reliability analysis, and tool degradation within manufacturing tool systems.

Beyond these efforts found in Mechanical Engineering and Industrial and Systems Engineering, Wayne State University has a diverse range of expertise to apply in making use of computing and smart sensor systems in advanced technology areas. In Computer Science, Wayne State University has an emerging faculty leader involved in vehicular wireless networking who has generated support from both NSF and industry. Other faculty in Electrical and Computer Engineering and Engineering Technology have been advancing use of sensor systems for modeling and control of electric grids, as well as modeling and testing of advanced battery systems for electric-drive vehicles through research thrusts in the alternative energy technology and electric drive vehicle engineering.

In Chemical Engineering, while there is a focus on advancing more biomedical-related research on nanocrystals and tissue engineering, there is also a substantial focus on advanced manufacturing topics. Among the larger (over $250,0000) research efforts are projects involved in biofuels development, advanced materials development of alloys, and multi-scale modeling of materials with applications for developing sustainable manufacturing and environmental impacts of energetic materials.

Wayne State University also has a long-standing expertise in transportation safety systems through its Department of Civil Engineering. This includes past and ongoing research into highway and transit operations and safety evaluation, highway risk management, GIS applications in highway and transit, transit management information systems, traffic calming strategies, transit-related seat belt, wheel chair lifts and vehicle replacement strategies, travel demand models, and railroad grade crossing safety. In addition, faculty in the Department of Biomedical Engineering conduct research in the biomechanics of motor vehicle occupants including development of human body models and testing of impacts of injuries and injury prevention.

Areas of Concern Regarding Wayne State University's Current Position in Advanced Manufacturing Research

One area of concern for Wayne State's research efforts in advanced manufacturing is its engagement with industry. There are certainly active university collaborations with industry and individual manufacturing companies. However, based on the level of industry-sponsored research within engineering at Wayne State this level of industry engagement is quite low—standing at 2.8% of its funding coming from industry compared to 8.3% nationally. Comparing Wayne State to other universities in Michigan as well as other universities involved in one of the major research centers that Wayne State is a participant, the U.S. Army TARDEC Automotive Research Center (ARC), it is clear that Wayne State's industry engagement is similarly lagging with other TARDEC ARC universities generating

an average of 8.5% in industry sponsored research funding for engineering and all other universities (including Michigan State) generating 7.8% in industry-sponsored research funding for engineering.

Table 1. Engineering R&D Expenditures by Source of Funds and Comparison Universities

Engineering R&D expenditures, by source of fund, 2012 (Dollars in thousands)					
Institution	**All R&D expenditures**	**Federal government**		**Business**	
		Expenditures	% of All Engineering	Expenditures	% of All Engineering
Wayne State University*	20,254	10,564	52.2%	563	2.8%
University of Michigan*	221,066	148,532	67.2%	16,941	7.7%
Oakland University*	4,620	2,535	54.9%	750	16.2%
Virginia Tech*	188,918	78,757	41.7%	15,934	8.4%
Clemson*	54,513	27,896	51.2%	6,070	11.1%
University of Iowa*	46,855	22,303	47.6%	2,321	5.0%
Michigan State	45,582	25,772	56.5%	1,514	3.3%
All Other Comparison Universities	561,554	305,795	54.5%	43,530	7.8%
Only Other Universities Involved in TARDEC ARC	515,972	280,023	52.4%	42,016	8.5%
* Universities involved with TARDEC Automotive Research Center Source: National Science Foundation, Academic R&D Expenditures, 2012					

Insights from Review of NSF Funding Programs and Industry Interviews

To further Wayne State University's goal of growing its overall College of Engineering, in part by advancing its position as a leading university in advanced manufacturing systems and digital design approaches, Battelle reviewed NSF funding programs for Advanced Manufacturing. In addition, Battelle integrated perspectives from leading manufacturing companies regarding research needs, talent needs and facility needs.

Cutting-Edge Issues for Advanced Manufacturing Systems and Design

NSF in its Advanced Manufacturing activities has a number of key focus areas that shows the breadth of what is needed in advanced manufacturing from the manufacturing production systems level to the machinery and equipment to the materials processing and design:

- **Manufacturing Enterprise Systems** focus on the design, planning, and control of operations in manufacturing enterprises. Topics of interest include supply chain optimization and management; production planning and scheduling; monitoring and control of manufacturing processes; and maintenance and repair. Of particular interest are methods that incorporate increasingly rich enterprise process and product information and models, methods that address sustainability, and methods that incorporate characteristic uncertainty and risk.

- **Engineering and Systems Design** is closely related to the Manufacturing Enterprise Systems, but support more theoretical studies of engineering design and an understanding of systems engineering. The program is focused on gaining an understanding of the basic processes and phenomena underlying a view of design where the system life-cycle context informs the identification and definition of preferences, analysis of alternatives, effective accommodation of uncertainty in decision-making, and the relationship between data, information, and knowledge in a digitally-supported environment.

- **Manufacturing Machines and Equipment** is focused on improving manufacturing machines and equipment, and their application in manufacturing processes. Key goals of the program are to advance the transition of manufacturing from skill-based to knowledge-based activities, and to advance technologies that will enable the manufacturing sector to reduce its environmental impacts. The program supports research on additive manufacturing, laser processing and bonding/joining processes encompassing feature scales from microns to meters, as well as conversion of biomass into energy products.

- **Design of Lightweight Engineering Material Systems** focus on new paradigms of design, development, and insertion of advanced engineering material systems. Of particular importance is advancing manufacturing processes for lightweight metal alloys and composites, including advanced high-strength steels, aluminum, magnesium, titanium, metal matrix composites, carbon fiber-reinforced polymer composites and combinations of these mixed-material systems. To create optimal microstructures for specific applications requires a fundamental

understanding of the operative mechanisms, as well as alloy-specific thermodynamic and kinetic information. The integration of experimental observations and modeling is enabling the development of new alloys, composites and processing methods where microstructure and properties can be controlled at the local level. This allows for the production of increasingly complex structures with optimal performance.

- **Materials Engineering and Processing** research is critical to address the processing and mechanical performance of engineering materials by investigating the interrelationship of materials processing, structure, properties and/or life-cycle performance for targeted applications. Of particular importance are the manufacturing processes that convert material into useful form as either intermediate or final composition. For lightweight materials, reducing the both the cost of primary material production and the cost of manufacturing using lightweight materials is critical to achieving mass reduction and affordability targets. In order to lower the cost of processes such as forming, casting, molding, machining, joining and assembly, cycle time needs to be reduced. In addition, the ability to predict performance for material, joints and parts would allow for optimized design while minimizing costs.

- **Nanomanufacturing** focus on the production of useful nano-scale materials, structures, devices and systems in an economically viable manner. It seeks to address quality, efficiency, scalability, reliability, safety and affordability issues that are relevant to manufacturing. To address these issues, the Program encourages research on processes and production systems based on computation, modeling and simulation, use of process metrology, sensing, monitoring, and control, and assessment of product (nanomaterial, nanostructure, nanodevice or nanosystem) quality and performance.

Discussions with industry in their needs for advanced manufacturing are generally in line with NSF in emphasizing:

- **Systems engineering** to improve manufacturability, including approaches to production and supply chain management.
- **Advancing industrial robotics and reaching next level of manufacturing automation**. Wide uses of robotics in manufacturing sought – both for continuous assembly manufacturing as well as specialized high value, low quantity components. Plus, interest in robotics for tooling and inspections.
- **Improved human-machine systems operation and interfaces**, such as augmented reality to help operator with tasks and advancing embedded systems.
- **Digital manufacturing design innovation** to go to market quicker with new products, aid in design and testing of products

Key Supporting Disciplines:

- Mechanical engineering, including automation and controls
- Industrial and systems engineering including modeling and simulation, electronic design, logistics

- Electrical and Computer Engineering, including power electronics, sensor networks
- Materials sciences and engineering, including metal forming technologies, composites, high temperature/harsh environments
- Chemistry and Chemical engineering, including integration of experimental expertise on battery technologies (electrochemistry), multi-scale modeling of materials, and bioprocessing for fuels as well as green chemistry
- Computer sciences, including Big Data, human interface, modeling systems, wireless communications

Critical Core Facilities and Specialized Equipment:

- While Wayne State has a number of core facilities and specialized equipment housed at the Center for Auto Research, the Advanced Composites Research Laboratory and the as well as facilities associated with the College of Engineering Auto Safety Group and Nanophonotics (advanced sensors), the required set of facilities for advanced manufacturing continues to be advanced.
- Among key facilities available at other universities involved in advanced manufacturing are:
- An Additive Manufacturing Systems Laboratory to further efforts in product design, process optimization and materials
- Importance of offering hard-to-find testing and characterization services emphasized, such as laser-based testing, advanced microscopy at macro level, high resolution transmission electron microscope (TEM), and X-ray inspection for dimensional analysis of small parts
- Large scale data visualization and simulation modeling lab (support multiple users and interactions)

Opportunity for Advanced Manufacturing and Digital Design for Automotive Industry and Broader Transportation Systems

The concern Battelle has in moving forward in this multi-disciplinary area of advanced manufacturing for Wayne State University is what companies, industry, or set of industries will the University more fully embrace in advancing its research activities. As mentioned earlier, this is increasingly a point of emphasis for federal research funding related to advanced manufacturing and a potential area of weakness at Wayne State University.

Clearly the advanced manufacturing industry in the Southeast Michigan region (Wayne, Oakland and Macomb counties) is dominated by the automobile industry and its variety of suppliers across advanced materials, industrial automation, precision machining, and engineering services. The bubble chart below sets out the high technology manufacturing industries across the three county area based on level of employment (size of the bubble), level of industry specialization (vertical axis) and recent industry employment trends since the economic recovery began in 2009. What it reveals is the continued strength of the automotive manufacturing industry and its associated supply chain in driving the economy in Southeast Michigan. The healthcare sector, led by hospitals and medical centers, is another

major employer and also stands out in terms of employment size. Information technology also appears to be an emerging area that is growing and is of considerable size. Beyond that, nearly all of the high tech industry base in the Southeast Michigan region—roughly 55% of the employment—is connected to the automotive industry.

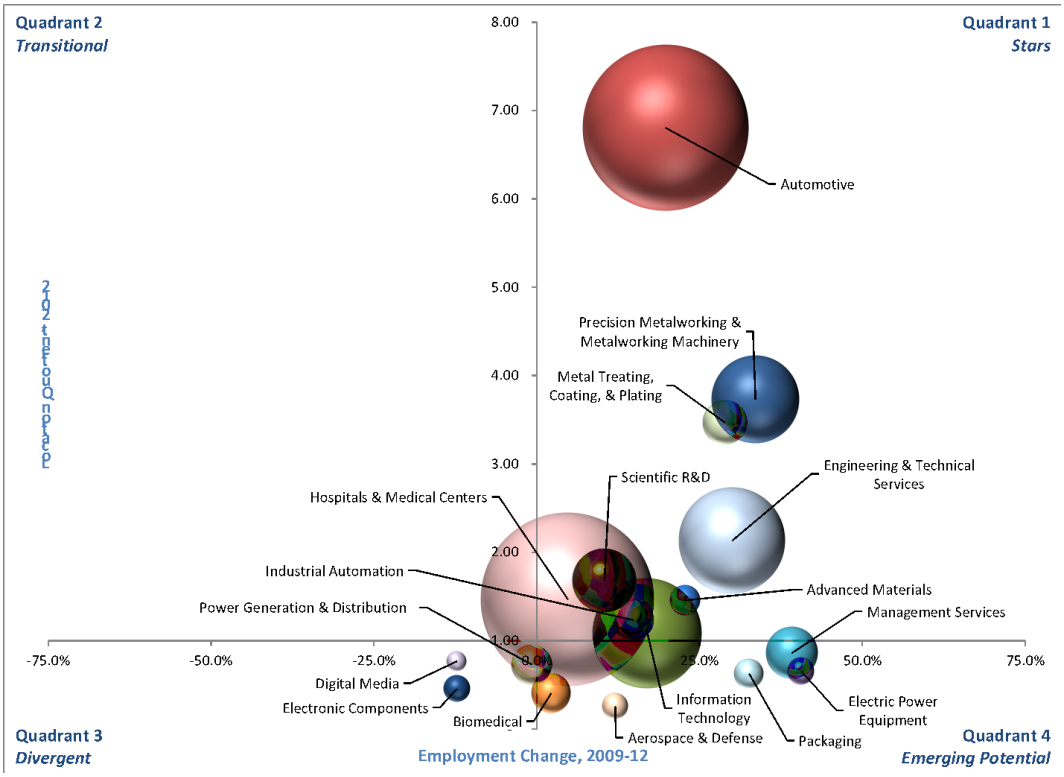

Figure 1. Post-Recession Recovery of the Southeast Michigan Region Industry Base

Source: Enhanced BLS QCEW Employment Data from IMPLAN, LLC; Battelle analysis.

As an innovation and R&D driver, the automotive sector (including its supplier base) is quite robust. Below Battelle sets out the level of innovation activities including patents and presence of emerging innovation-oriented companies (from a variety of sources) across high technology industry drivers. What distinguishes the automotive sector is its emphasis on existing companies compared to the rise of more emerging companies, though in associated industries of advanced materials, engineering & technical services and energy & power the importance of emerging innovative companies dominates. This emphasis on emerging innovation companies is also strong in non-automotive related industry drivers including information technology, management services, biomedical and scientific R&D.

Table 2. Identification of Innovation Activities Across Industry Base of the Southeast Michigan Region

Technology Industry	Presence of Firms Involved in Innovation Activities	Presence Across Activities (one firm can be in more than one area)			
		Patents	SBIR	Venture Capital	Engaged with Other Michigan Specific Start-up Activities
Automotive and Related Supply Base					
Automotive Technologies	76	63	4	3	13
Engineering & Technical Services	27	2	8	1	20
Energy & Power	17	2	1	1	21
Advanced Materials	17	7	4	2	8
Other Technology Industry Drivers of Innovation					
Information Technology	100	4	3	15	110
Biomedical	44	7	10	9	41
Management Services	31	4	5	7	24

Scientific R&D	28	5	7	4	27

Notes and Sources: Intellectual property generation measured by patents from 2009 to 2013, Delphion Patent System; Federal Small Business Innovation Research Awards from 2009 to 2013, U.S. Small Business Administration; Venture capital funding from 2009 to 2013, Thomson Venture One; Remainder based on: Other innovation capital investment sources, such as MEDC, Automation Alley, NextEnergy; Located in business incubators and accelerators, such as Bizdom, Grand Circus, and Tech Town; and Identified technology start-ups by New Economy Initiative.

As a leading R&D state, the importance of the automotive sector also comes through. While Michigan is one of our nation's top five states for industrial R&D – with $13.5 billion of R&D company-funded R&D performed in 2012 – the automobile, bodies, trailers and parts industries account for 75% of this industry R&D.

So the question stands whether the automobile sector is a good place for Wayne State University to focus growing industry research relationships. This comes down to several key factors:

1) Is the automotive sector an active player in advanced manufacturing changes taking shape?

2) Is there an ability to leverage beyond the automotive sector to other industries?

3) Is the automotive sector a good source of industry-related R&D for universities?

In regards to being an active player in advanced manufacturing changes, the automotive sector is at the forefront of many of the changes taking place in advanced manufacturing. A recent McKinsey Quarterly article on "A Road Map to the Future of the Auto Industry" noted:

"Digital design and manufacturing can raise productivity in a dramatic way: big data simulations and virtual modeling can lower development costs and speed up time to market. That should resonate with customers conditioned to the innovation clock speed of consumer electronics, such as smartphones. Common online platforms can connect supply and demand globally to increase the efficiency of players across the supply chain. Embedded data sensors should enable more precise monitoring of the performance of vehicles and components, suggesting new opportunities for lean-manufacturing techniques to eliminate anything customers don't value and dovetailing with the digitization of operations to boost productivity, including the productivity of suppliers, in unexpected ways."[5]

While most of the automotive industry's innovation is focused on areas such as smart vehicle technologies (e.g., vehicle navigation, location, and avoidance systems), engine and transmission development, and other vehicle components, the industry is also at the forefront of many of the leading technology advances within broader manufacturing including digital design, lightweight materials, new coatings and adhesives, battery development and power electronics.

On the question of ability to leverage beyond the automotive sector to other industries, the range of technologies being advanced to meet the needs of the automotive industry would suggest there is an opportunity. However, the automotive industry is not always the first adaptor of new emerging

[5] Gao, Hensley and Zielke, "A Road Map to the Future for the Auto Industry," McKinsley Quarterly, October 2014

technologies. For instance, in lightweight materials, McKinsey reports that 80% of the aviation industry use of materials in 2010 is comprised of light metals, aluminum, plastics and composites – significantly ahead of other industries. This is also true in additive manufacturing, where the high volume requirement of the automotive sector is not able to be addressed yet by this emerging technology[6]. Still, the automotive market is likely to be a very large user of lightweight materials and potentially a significant user of additive manufacturing for vehicle customization and, in fact, there is considerable research and development needed to advance these technologies so that they can be used in the higher volume-based automotive industry. Plus, as these technologies are advanced in the automotive sector, they open up the door to other more mass-produced industries.

But an even more important spillover in being involved in the next wave of automotive advanced manufacturing innovations is its impact more broadly on transportation systems. In particular the integration of smart technologies goes well beyond just the production of transportation vehicles and impacts the overall transportation system. Connected vehicle technology, according to the U.S. Department of Transportation, has the potential to transform the way Americans travel through the creation of a safe, mobile and environmentally friendly interoperable wireless communications network—a system that includes cars, buses, trucks, trains, traffic signals, cell phones, and other devices.[7]

This growing competency in advancing key components, systems and processes used in transportation vehicle manufacturing together with connected vehicle technology and smart transportation systems offers a strong line of sight to focus Wayne State University's existing research capabilities on the use-inspired and translational research challenges of Michigan's advanced manufacturing economy. One particular area where this integration will be felt is in the area of transportation safety where Wayne State University already has an active research portfolio. Most encouraging is that Wayne State University has already taken an important step to ***broaden its interdisciplinary research focus in transportation safety through the formation of the Automotive Safety Group (ASG) in 2013***. ASG bring together interdisciplinary teams from the College of Engineering, College of Liberal Arts and Science, School of Medicine, and College of Pharmacy and Health Sciences to perform research to reduce auto-related crashes and minimize the risk of injury in auto accidents. ASG's research areas of focus include:

- Autonomous Driving and Vehicle Communication
- Driver Behavior and Simulation
- Sensor and Algorithm Development
- Crash Worthiness
- Injury Biomechanics
- Smart Material and Manufacturing

[6] It should be noted that the automotive industry was an early adopter of rapid prototyping, the precursor to modern additive manufacturing technologies.

[7] See more at http://www.its.dot.gov/safety_pilot/index.htm

This automotive safety area also offers a potentially strong and established industry association, the Automotive Safety Council (ASC), with over 35 industry members, across major systems suppliers, component suppliers, materials suppliers and others. The ASC might provide a robust and diverse industry group with which to partner for new research initiatives.

Finally, on the third question of whether the automotive sector is a good source of industry-sponsored research for universities, the question boils down to compared to what? In 2008 the automotive industry invested about $25 million on R&D performed by academic institutions. As U.S. manufacturing headed into the Great Recession one of the first budget cuts made by most manufacturers was sponsored research to universities. These expenditures likely haven't returned to anywhere near pre-recession levels. Using the 2012 NSF Business Research, Development and Innovation Survey (BRDIS) data, some sense of this decline can be estimated for the automotive industry. For 2012, U.S. automotive/supplier firms spent about $13.2 billion of their own funds on R&D in the U.S. Of this amount, about $2.4 billion was spent on R&D performed by others (e.g., they paid some entity outside their company to perform the R&D). Of this about $1.7 billion was performed by other U.S. companies and $770 million by foreign companies. Only about $2 million was spend with "In U.S. - All Other" entities which in the 2012 survey is primarily Colleges and Universities.[8]

It is also important to recognize the importance of research relationships with the supplier base when considering pursuing automotive research funding. While the automotive OEMs likely constitute a large share of the sector's $13.2 billion R&D total, major first and second tier suppliers are also included in this total. Additionally, the majority of the R&D funding from the U.S. automotive sector to outside organizations went to other U.S. companies – approximately $1.7 billion or 68% of the total externally funded R&D. This suggests the importance of working with innovative automotive sector companies, beyond the OEMs, whether in lightweight materials, battery technology or engineering services.

But the higher levels of industry-sponsored research from other universities involved in automotive research with Wayne State University suggests it might be possible to advance research capacities that attract industry-sponsored research**.** As pointed out earlier, other universities participating in the TARDEC Automotive Research Center along with Wayne State University have much higher levels of industry-sponsored research in engineering. While it is not possible to identify the precise industry sources, it is likely to be at least partially related to research capacities advanced in connection to federally funded research.

It is clear that while the post-recession automotive industry may continue to be a limited direct source of R&D funding, it is a viable and important sector for pursuing industry relationships to leverage federal R&D funding. With the shifting focus of federal advanced manufacturing research funding placing a higher priority on universities having an industry facing research approach, the automotive industry and its broader supplier base is a valuable partner. This is not to say that there might be other industry sectors that Wayne State can identify.

[8] Within the 2012 BRDIS survey "All Other" (U.S. and Foreign) is the level of performed R&D remaining after self-performed, performed by other companies, and performed by state/federal/foreign governments are taken into account.

Already the automotive sector is a large focus for what advanced manufacturing industry relationships exist at Wayne State, but it is not generating significant sponsored research compared to other universities. For instance, Wayne State has an Engineering Management Master's Program in collaboration with Ford Motor Company that has more than 300 graduates since 1995, which involves a capstone project involving an applied research problem and so exposes Wayne State faculty to key industry concerns and the future cadre of engineering leadership at Ford. But this has not translated into a source of sponsored research activities.

One way to achieve increased research relationships is to enhance Wayne State's capabilities in a target area of advanced manufacturing – whether it is lightweight metals or battery technology or safety for smart automobiles -- that Wayne State can be among the national leaders and so attract interest from industry, whether it be automotive or other manufacturing sectors. In the context of having a strong capability in a focus area of advanced manufacturing, it will be more likely that the broader research activities found at Wayne State University, such as its systems engineering or its wireless sensors can then be leveraged to complement that area of strength in offering more integrated solutions.