NSF Workshop on Research needs in Advanced Sensors, Controls, Platforms, and Modeling (ASCPM) for Smart Manufacturing

Atlanta, Georgia

February 23-24, 2015

Organizers

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Acknowledgments

The workshop organizers wish to recognize the participants of the workshop and the assistance of Dr. Ed Gatzke for compiling the results of the workshop. Participant comments and input were used directly in the production of the summary report. The workshop organizers also wish to acknowledge the support from the National Science Foundation Chemical, Bioengineering, Environmental, and Transport Systems Organization within the Directorate of Engineering for the financial support of this workshop under Grant No. 1523237.

Summary

Smart Manufacturing and *Digital Manufacturing* are the evolving descriptors for the business and operational application of advanced cyber technologies in manufacturing. The term 'Manufacturing' refers to anything that is 'made' - energy, chemicals, materials, and objects. This workshop brought together experts in smart manufacturing and digital manufacturing, industry, and academia, cutting across the sectors of continuous, batch, discrete and hybrid manufacturing. The workshop objectives during 2/23-24/2015 were to build a common understanding and use of terminology and to then delineate research areas and opportunities with greater precision. The workshop report is an independently developed assessment and summary of the results reflecting a consensus by each breakout group on relevant definitions and research areas and their scope. A key outcome of this workshop is the expression of the report structure itself – (1) the semantics of Smart Manufacturing and Digital Manufacturing, (2) the fundamental role of modeling and (3) the particular descriptions of the ASCPM research areas. The workshop addressed the following key ten questions about advanced sensors, controls, platforms, and modeling (ASCPM) for Smart Manufacturing:

(1) What are crisp definitions/meanings that capture the semantics of advanced manufacturing: Sensing, Control, Automation, Platform, Visualization, Informatics, Digital Thread, Design vs. Operations, Life Cycle, Model Integration
(2) What are key attributes that define Smart Manufacturing vs. Digital Manufacturing?
(3) What modeling, data and infrastructure elements overlap and/or intersect?
(4) What are the key fundamental research challenges in sensors and monitoring, controls and processes, platforms and standards, and supply chains and scheduling; and how do they relate to different manufacturing and enterprise structures – continuous, batch and discrete (building off AMP 2.0 workgroup summaries)?
(5) What roles do models play in addressing research challenges?
(6) What are the needs in visualization and data informatics in each area?
(7) How do research needs impact platform infrastructure requirements?

(8) What are the potential impacts of ASCPM R & D on energy efficiency/carbon emissions, environment and safety?
(9) What are compelling industrial vignettes for ASCPM successes?
(10) What are the sensor, control, platform and software barriers to achieving success?

The Appendices included in this report contain particularly valuable detailed information and insights. Great care was taken to include the direct results in the Appendices from each of many breakout sessions designed to bring different viewpoints together in answering specific questions. The reader is encouraged to validate the summary with the detailed results in the Appendices.

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NSF Workshop: High Priority Research Areas on Integrated Sensor, Control and Platform Modeling for Smart Manufacturing

Atlanta, GA

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Background and Introduction

In October 2014, the President's Council of Advisors on Science and Technology (PCAST) released the report of the Advanced Manufacturing Partnership (AMP) 2.0 Committee entitled, "Accelerating U.S. Advanced Manufacturing". The report motivated next generation advanced manufacturing focusing on enabling innovation, securing the talent pipeline, and improving the business climate for U.S. growth and competitiveness. The report further identified and recommended the alignment of efforts and resources to address next generation advanced manufacturing IT infrastructure technologies critical to U.S. competitiveness, encompassing growth, dynamic performance, energy and material usage, environmental sustainability and zero incidents. Advanced Sensing, Control, and Platforms for Manufacturing (ASCPM) and Visualization, Informatics, and Digital Manufacturing Technologies (VIDM) were presented as comprehensive technology priorities:

> **"Advanced, Sensing, Control, and Platforms for Manufacturing (ASCPM):** A new generation of network based information technologies has created access to new uses of data and information as new products and manufacturing methods are developed. These technologies make a seamless interaction between cyber and physical assets possible. The research in this space is focused on embedded sensing, measurement and control systems with scalable IT platforms."

> **"Visualization, Informatics, and Digital Manufacturing Technologies (VIDM):** This technology is important as researchers and manufacturers move from digital design, to planning, to purchasing and delivery of raw materials, and finally to the manufacture of customized products. One aspect of the technology deals with supply chain efficiency, and the other aspect deals with the speed with which products are designed, manufactured and brought to market. The research in this space is focused on sensing, measurement and control systems embedded into materials and technologies. When this link is strong, it increases productivity, product and process agility, environmental sustainability, improved energy and raw material usage, better safety performance and improved economics."

Smart Manufacturing and *Digital Manufacturing* are the evolving descriptors for the business and operational application of these advanced cyber technologies in manufacturing. The term 'Manufacturing' is, itself, used to reference anything that is 'made' - energy, chemicals, materials, and objects. As defined in the recent AMP 2.0 workgroup reports that supported the PCAST/AMP 2.0 report, technologically, Smart Manufacturing encompasses ASCPM while Digital Manufacturing, Visualization and Informatics are closely aligned, emphasizing life cycle design innovation. While generally still early in adoption, enterprise implementation of ASCPM and Smart Manufacturing has seen somewhat wider adoption in the chemical and process industries while VIDM and Digital Manufacturing have been applied more in the discrete product and assembly industries.

When taken together the respective Smart Manufacturing and Digital Manufacturing cyber technologies areas can reflect technology differences because of different drivers. However, significant overlaps and complements occur depending on the layer and method of technology deployment (see Fig. 1). It is well established that product design, manufacturing process design, product life cycle planning, manufacturability, and the actual manufacture and delivery of a product or material are interlinked regardless of continuous, batch and discrete manufacturing structures. As advanced physical manufacturing technologies progress in areas that include process intensification, new energy sources and new materials processes, energy grid, and 3D printing, there is significantly increased emphasis on product customization and value, dynamic and agile performance, and product acceleration and innovation , which are all amplified in the development and application of models.

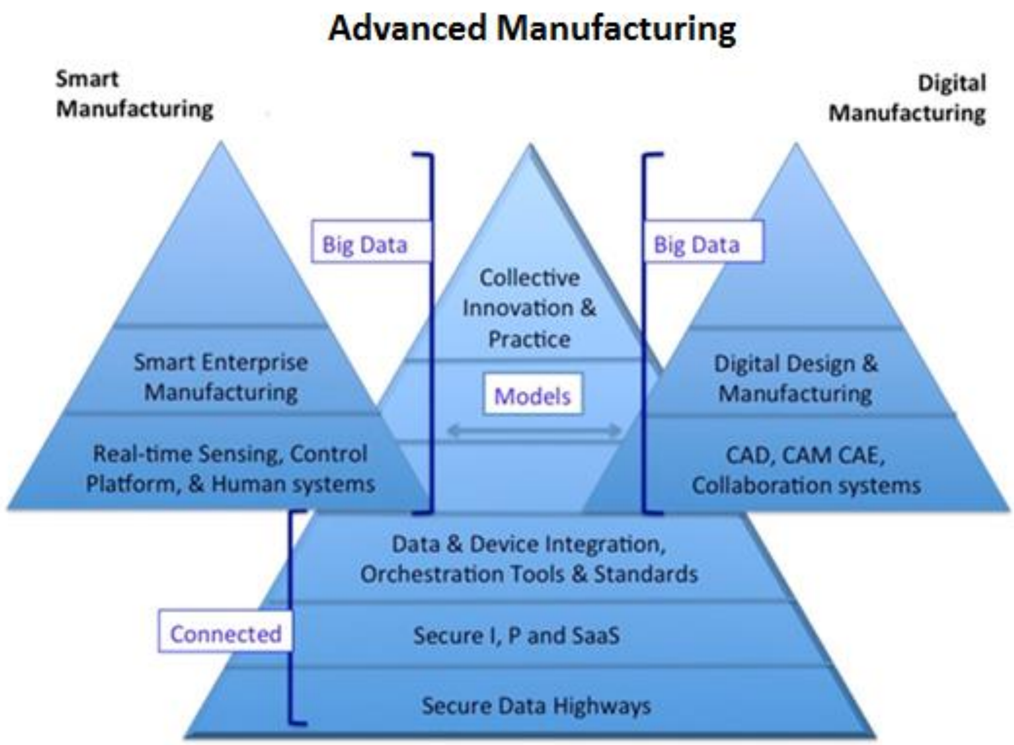

Figure 1: Parallel Connections of Smart Manufacturing and Digital Manufacturing

In planning this workshop, Dr. Thomas F. Edgar (Co-Chair, UT) and Dr. Jim Davis (Co-Chair, UCLA) worked with an interdisciplinary team of 10 people: Michael Baldea (UT), Maria Burka (NSF), Iiro Harjunkoski (ABB), Tom Kurfess (GA Tech), Christos Maravelias (UWisconsin), Stephen Prusha (JPL), Alex Reed (Tulane), Tariq Samad (Honeywell), Shreyes Melkote (GA Tech), and Denise Swink (DOE retired). Julie Tran (UCLA), Brenda Greene (GA Tech), and Kristine Poland (UT) provided planning support for the workshop as well as generated workshop documents.

The February, 2015 workshop at Georgia Tech (Atlanta, GA) considered real-time sensing, control, platform systems, and cyber technologies. The ASCPM components relate to the manufacturing process and are mutually linked with visualization digital design and manufacturing (VIDM). The workshop assembled research and industrial experts from a cross section of continuous, batch, discrete, and hybrid manufacturing interests (see Appendix I). These individuals represent a cross-section of experts in the application of real-time enterprise smart and digital manufacturing technologies, including real-time process management, online control, process simulation, advanced modeling, data analysis, supply chain management, product improvement, and production design optimization. An important objective was to understand how these interlinked cyber technologies are appropriately balanced and integrated for continuous, batch, and discrete industry applications with a view toward next generation manufacturing technology trends.

The agenda is shown below. Four breakout groups for each session were constructed so that diverse points of view were obtained from academia, government, chemical engineering, and mechanical engineering, and types of industries (batch, continuous, and discrete). Specific questions were posed for each breakout session, as shown in the agenda.

Workshop Agenda

Day 1 – Setting the Context

10:00 am **Keynote: Smart Manufacturing and Digital Manufacturing—New Research Directions Arising from AMP 2.0**
Tom Kurfess (Georgia Tech) and Ravi Shankar (Dow Chemical)

11:00 am **Breakout Session 1-Smart Manufacturing Semantics**

Question 1: What are crisp definitions/meanings that capture the semantics of advanced manufacturing: Sensing, Control, Automation, Platform, Visualization, Informatics, Digital Thread, Design vs. Operations, Life Cycle, Model Integration

Question 2: What are key attributes that define Smart Manufacturing vs. Digital Manufacturing?

Question 3: What modeling, data and infrastructure elements overlap and/or intersect?

2:00 pm **Breakout Session 1 Reports**

2:30 pm **Break**

3:00 pm **Breakout Session 2-Fundamental Research Needs for ASCPM**
Breakouts organized by (S) sensors and monitoring; (C) controls and processes; (P) platforms and standards; and (SC) supply chains and scheduling.

Question 1: What are the key fundamental research challenges in each area, and how do they relate to different manufacturing and enterprise structures – continuous, batch and discrete (building off AMP 2.0 workgroup summaries)?

Question 2: What roles do models play in addressing research challenges?

Question 3: What are the needs in visualization and data informatics in each area?

Question 4: How do research needs impact platform infrastructure requirements?

5:30 pm **Break for dinner (self-organized), prepare reports**

Day 2 – Setting the Stage for Research Needs in SM

9:00 am **Breakout 2 Leaders Summarize Day 1 Conclusions and Findings**

10:00 am **Observations on Research Needs (Industrial/Academic Panel)**

11:00 am **Discussion (Full Group)**

12:00 pm **Breakout Session 3-Other Dimensions of Near and Long-range R&D Opportunities**

Question 1: What are the potential impacts of ASCPM R & D on energy efficiency/carbon emissions, environment and safety?

Question 2: What are compelling industrial vignettes for ASCPM successes?

Question 3: What are the sensor, control, platform and software barriers to achieving success?

Question 4: What Apps could be broadly used for ASCPM?

2:00 pm **Breakout Reports and Closing Comments**

3:00 pm **Depart**

The detailed summaries from each breakout session and the keynotes are included in Appendices II-VI. Copies of presentation slides are also included there. Below we summarize perspectives and conclusions from the workshop. Multiple points of view are included since achieving a consensus was not considered to be a feasible goal for the workshop. On the second day of the workshop, distinguished industrial/academic panel reacted to the findings of the second breakout session; comments are recorded in Appendix IV. Finally the workshop concluded with impacts of SM on energy and the environment and identified barriers to achieving success (Appendix V).

Smart Manufacturing and Digital Manufacturing

After keynote presentations by Dow Chemical Company and Georgia Tech (see Appendix VI), the workshop moved to refine the definitions of smart manufacturing and digital manufacturing (see Fig. 2). The resulting definitions were heavily influenced by the background of the participants. One obvious difference was seen between groups with a background in discrete manufacturing (such as Automotive) and those with a background in continuous processes (Chemical Production). A general consensus found that "Advanced Manufacturing" is a more comprehensive and encompassing term that can include continuous and batch processing and discrete production.

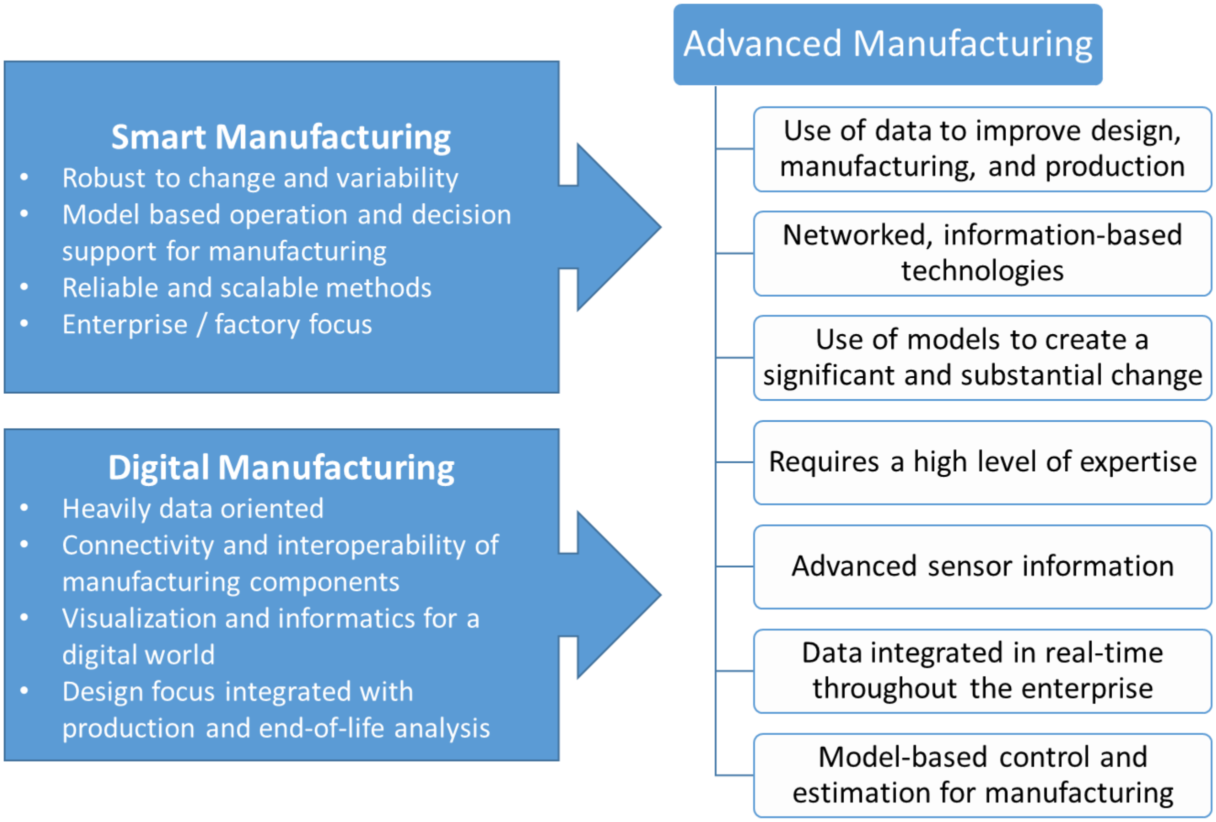

Figure 2: Attributes of Smart, Digital, and Advanced Manufacturing

Modeling: The Underlying Foundation of ASCPM

Modeling in the most general sense is the use of a mathematical description to simulate and analyze a physical system. Models can be used at every point in the product life cycle. Design models are used to optimize a product and investigate product quality, reducing the requisite amount of expensive or impossible experimental validation. Models are also used in manufacturing for control and operation. Models may also be used post-production to examine degradation and disposal issues. Models can represent a product, a manufacturing process, or a business activity.

Models in support of advanced manufacturing must meet many requirements. Ideally, federated models would be developed for the product. The product model could incorporate CAD drawings, consumer requirements, experimental data, and simulation results. This product model could be incorporated with models of the production process. Production method limitations will influence product design. Product models and production process models could be used for advanced manufacturing cyber applications. During the manufacturing process, mathematical models tied to advanced sensing will provide decision support. Models are also necessary for control of the manufacturing process, use of online fault monitoring methods, and implementation of state estimation techniques. At a higher level, plant-wide or industrial-scale models can also tie into product and process models to improve quality and efficiency by supporting business decisions. Models are currently used for many different applications, but in many cases little has been done to integrate modeling efforts. This results in significant duplication of effort and lengthening of the product cycle.

There are many diverse goals for developing models. Sensing and modeling could be combined during manufacturing to provide additional information to the producer and consumer. Models should provide an intuitive level of abstraction, as models can be developed at many scales, describing everything from molecular interactions to business-wide distribution networks. Practitioners will decide what to model, how to create the models, and the right level of accuracy for the models. Ideally, modeling efforts would be simple to implement, requiring limited time, effort, and advanced knowledge to implement. An overall modeling framework should be able to readily accommodate a wide range of integrated design, production, and business operations.

To make improvements in advanced manufacturing, a platform infrastructure should be made available. A general purpose platform could serve as the backbone of an advanced manufacturing effort, allowing for the various modeling activities to grow and develop (see Fig. 3). Platform requirements describe the cyber infrastructure that will allow interoperability and connectivity of the various modeling components.

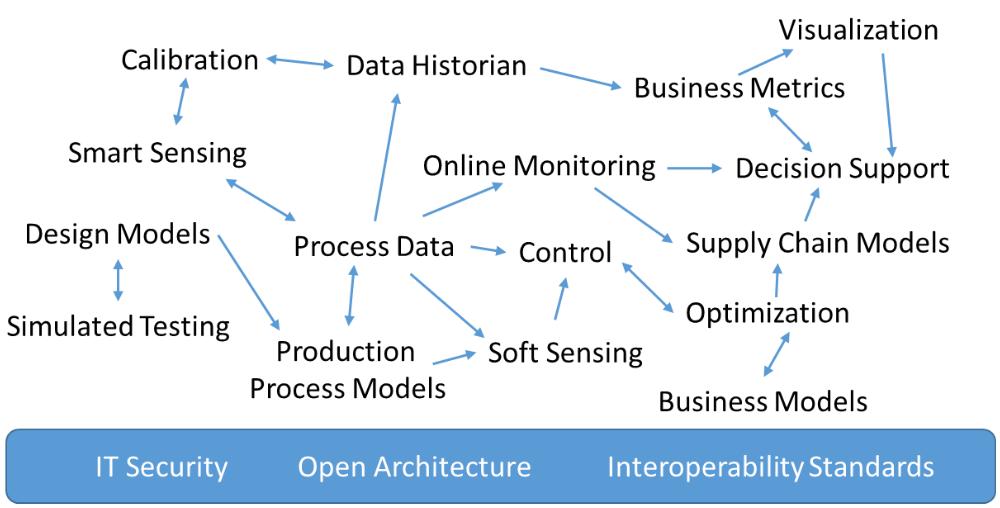

Figure 3. The Ubiquity of Models and Data in Advanced Manufacturing

New Areas of Research for Smart Manufacturing

Sensors and Monitoring - Low-cost sensing technology will play a key role in future development for smart manufacturing. This measurement data is key to making improvements in the manufacturing process. Smart sensing includes new sensing methods, real-time process analysis, wireless connectivity, and sensors integrated with new cyber technologies. These advanced sensors may be able to autonomously manage and evaluate sensor health, continuously quantify measurement uncertainty, and support efficient calibration procedures. Smart sensors enable a wide range of advanced manufacturing capabilities. Product sampling for quality control testing can be reduced when advanced measurement information is properly integrated into the production process. Sensors provide information for validation and improvement of models. A mathematical model has limited use until measurements are used for model validation. As a system changes with time, process sensor values can be used to update the process models, allowing for various advanced manufacturing improvements. Additionally, better sensing leads to quantification of process variability and uncertainty. Improvements in sensor capabilities and industrial networking will provide large amounts of data. This "big data" problem leads to issues related to visualization and informatics. Without strong visualization and analysis techniques, big data can result in limited usefulness. Data compression and data security are also relevant issues that must be addressed. Practical concerns include integration of new sensor systems with legacy machines and processes. Sensor calibration and maintenance are also real-world problems that could have substantial impact in industry. See Appendix II for more details.

Control and Automation - Control and automation systems use computers to make improvements in a manufacturing process. Process improvements can include increased efficiency, lower cost, higher throughput, and lower variance. Advanced control systems require accurate process models. Opportunities exist for smart control and automation to support optimal decision making, enterprise modeling, and process analytics. Current technologies do not readily support rapid integration across various business and production applications. Simulation based control strategies such as model predictive control can be used to improve the production process. Future control methods should better support short-term scheduling, longer-term planning, and economic optimization. Control and automation would also benefit from improved modeling efforts. Process information is not typically available across all levels; design information is not always used for manufacturing and manufacturing information is not used to develop control or monitoring systems. Data at all levels should be orchestrated, available, and used by various applications and services. Applications and services should be interoperable and extensible. Process monitoring is a relevant segment of control and automation where data and models are used to diagnose abnormal situations while helping in mitigation of negative consequences. See Appendix III for more details.

Supply Chains and Scheduling - Supply chain management challenges include improving the models used to represent the manufacturing systems. In particular, the lack of formal models for representing large-scale discrete manufacturing facilities was emphasized. In a different vein, more efforts should be directed towards capturing, characterizing and mitigating uncertainty in the operation of manufacturing systems (caused, e.g., by variability of orders and deliveries, but also, increasingly, by fast fluctuations such as those observed in, e.g., energy prices). The use of historical data for improving system models and uncertainty models should be extended, and methods for verifying the quality of solutions obtained by accounting for uncertainty should be developed. Moreover, these modeling and analysis efforts should be directed towards systems of ever larger scale; as a complementary direction, significant work will be required to expand the capabilities of current numerical optimization algorithms, such that very large scale problems can be addressed in practical amounts of time.

Platforms and Standards - encompass machine-to-process-to-plant-to-enterprise-to-supply-chain aspects of sensing, instrumentation, monitoring, control, and optimization, including hardware and software platforms for industrial control and automation. A new generation of networked based information technologies, data analytics and predictive modeling is providing unprecedented capabilities as well as access to previously unimagined potential uses of data and information not only in the advancement of new physical technologies, materials and products but also the advancement of new, radically better ways of doing manufacturing, processing materials and interoperating with material and energy resources The platform is the informatics infrastructure that allows industry to develop and deploy relevant smart applications. This allows for consistent applications to be joined together, even between businesses. Open interfaces, protocols, and standards will aid in platform development, allowing for plug-and-play interoperability in the platform. In focusing on the manufacturing or production stage of the product life cycle, platform technologies are strategically as important for U.S. manufacturing as are the design, new product and digital thread technologies. They offer the technical elements needed in smart manufacturing that is about enabling seamless interoperation of cyber and physical assets to increase productivity, product and process agility, environmental sustainability, energy and raw material usage, and safety performance as well as economic performance.

Platform infrastructure is particularly well suited for supporting and facilitating hybrid systems methodologies among design, control and orchestration in heterogeneous environments. In design, system, material, and product design models validated for manufacturing application can be accommodated as real-time analytic, model, and simulations to provide decision support or insertion in control and automation plans. A Smart Manufacturing (SM) platform supports reuse and ready application of models and analytics at the level of need and readiness. By incorporating these methodologies, design models become a major source of software through the SM Platform Marketplace and the systems risk based methodology for resourcing and building models provides a verification, validation, and certification process for the models. In reverse, the SM Platform similarly supports a mechanism to identify, exercise, and evaluate emerging manufacturing technologies from research organizations, as model elements of larger scale commercial system design emerge. The infrastructure allows for virtual test and analysis in early design phases using model representations in a free market library available to qualified commercial entities. The SM Platform also provides a pathway to think about new scaled modeling methods that include not only a build up to broad enterprise analytics but the ability to model the impacts of scaled infrastructure for the enterprise. See Appendix III for more details.

Digital Manufacturing – Somewhat different from Smart Manufacturing, Digital Manufacturing focuses on the use of integrated, computer-based systems comprised of simulation, three-dimensional (3D) visualization, analytics and various collaboration tools to create product and manufacturing process definitions simultaneously. Manufactured artifacts move seamlessly through conception, design modeling, analysis and manufacture. *Digital Thread* is often associated with Digital Manufacturing referencing the integrated chain of data from conception to manufacture to end product, i.e. the design to manufacturing product lifecycle. Digital Manufacturing objectives are concentrated on new products and shortened design to manufacturing life cycles and new product changeovers. Time is about more design options in reduced time and reduced time to market. Digital Manufacturing addresses energy with new products and materials that lower energy requirements at the user level and are recyclable. Modeling is focused on design, prototyping, and use of CAD, CAE and CAM technologies and facilitation of a digital thread. See Appendix II for more details.

Visualization, Informatics, and Digital Manufacturing (VIDM) is the set of integrated, cross-cutting enterprise-level smart-manufacturing methodologies leveraging information technology systems that will improve U.S. manufacturing competitiveness through end-to-end supply-chain efficiency, unprecedented flexibility, and optimized energy management to achieve error-free manufacturing of customized products and components from digital designs, when needed and where needed. The key drivers of VIDM are: 1) Increased R&D and manufacturing integration with end to end speed and productivity, supply chain efficiency, process yields, energy efficiency, improved sustainability; and 2) Improved process safety, flexibility, agility, configurability, and increased job satisfaction and pride. VIDM is focused into three sub-areas – Digital Thread; 2) Integrated Information Systems; and 3) Manufacturing Big Data and Analytics. See Appendix II for more details.

Modeling – Advanced modeling cuts across and unifies all of the areas mentioned above. Process models and product models are moving toward more complexity. Large-scale models attempt to provide a much higher level of detail. Methods for using hierarchical and distributed approaches could enable significant improvements. This can be seen in efforts to extend models from 1D or 2D to 3D which often leads to computational complexity. Increased sensing and access to data leads to problems related to unstructured information, correctness verification, model clarity, and model resilience. Development of large-scale, hierarchical, high fidelity models presents challenges for process control and optimization. Specifically, advancements could be made in control of difficult (nonlinear, stochastic, hybrid) systems, planning, and use of unstructured information. There is a perceived gap between models used for process scheduling and for process control. Methods should also attempt to account for uncertainty in operations in order to allow for robust operations. For example, historical data could potentially be used for determining the extent of model uncertainty. Uncertainty leads to difficulty in verification of process control and optimization solutions. Additionally, uncertainty in cost variability is rarely included in scheduling and optimization work.

The potential of mutually supportive intersections is evident with existing and new comprehensive systems modeling methodologies that extend model breadth beyond traditional process simulations or traditional CAD based geometrical designs to include integrated programmatic, system interfaces, multi-dimensional risk, supply chain, environmental, and other market features. In result, the product and system design model can evolve as a full lifecycle construct from conceptual design through manufacturing and operation in a rapid fashion. Models and simulations that have been driven in traditional ways give way to systems-defined models that are direct reflections of the product or material and the manufacturing process. Planning resources for design models are allocated relative to design, planning, and operational risks. These risks in turn determine the level of model fidelity needed. During manufacturing, data from suppliers as well as the factory floor are integrated with these models of product and process performance to produce significantly better-informed decisions and predictions of operational and business performance. In conducting design and planning processes with this system and risk perspective, the materials and design models are by definition ready for production and can serve a range of manufacturing objectives that include source material or product qualification, in production material and process qualification, and a range of enterprise operations and optimizations. As risks are addressed and new bottlenecks and opportunities become apparent, the models can be updated for these new risks and at the same time remain viable for production use.

Intersections are also evident with Smart Manufacturing modeling that supports cross seam modeling situations such as human-in-the-loop involvement, enterprise modeling where first principles models are typically unavailable or insufficient, modeling when there is insufficient information or exemplars to build data-based models and modeling when there is a need to mix or merge different kinds and sources of data including numeric and symbolic forms. This form of modeling supports cyber tasks that need to be decomposed when they cannot readily be formulated as time integrated and synchronized or need different resources to achieve and provides a construct for stitching or linking applications and/or data heterogeneous environments. This is contrasted with smart control and automation modeling, which is characterized by sensor-to-actuator models and associated physical facilities that function within a common time frame that has been defined a priori. Cyber tasks, physical actions and system resources are well-defined in time and tightly integrated such that time and data collection rates are synchronized by the fastest physical operation time constant needs.

Appendix I. Workshop Attendees

Name	Affiliation
Baldea, Michael	UT Austin
Bartles, Dean	Digital Manufacturing and Design Innovation Institute (DMDII)
Bequette, Wayne	Rensselaer Polytechnic Institute (RPI)
Braatz, Richard	MIT
Burger, Ken	Owens Corning
Burka, Maria	National Science Foundation (NSF)
Calloway, Bond	Savannah River National Laboratory (SRNL)
Chiang, Leo	Dow Chemical
Cohen, Paul	North Carolina State University (NCSU)
Daoutidis, Prodromos	Univ. of Minnesota
Davis, Jim	University of California, Los Angeles (UCLA)
Dods, Bryan	General Electric (GE)
Edgar, Tom	UT Austin
Ehmann, Kornel	Northwestern
Farschman, Chad	Owens Corning
Fonda, James	Boeing
Gatzke, Ed	University of South Carolina
Gotkin, Alisono	United Technologies Research Center (UTRC)
Harjunkoski, Iiro	ABB
Harris, Greg	Digital Manufacturing and Design Innovation Institute (DMDII); U.S. Army
Huang, Ninja	General Motors
Ierapetritou, Marianthi	Rutgers University
Joshi, Mak	Schneider Electric
Kapoor, Shiv	University of Illinois at Urbana–Champaign (UIUC)
Kurfess, Tom	Georgia Tech
Kushnerick, Doug	ExxonMobil
Leiva, Conrad	Manufacturing Enterprise Solutions Association
Li, Xiaochun	UCLA
Lu, Yan	National Institute of Standards and Technology (NIST)
Malkani, Haresh	Alcoa
McGinnis, Leon	Georgia Tech
Megan, Larry	Praxair, Inc.
Melkote, Shreyes	Georgia Tech
Melton, Ron	Pacific Northwest National Laboratory (PNNL)
Moshgbar, Mojgan	Pfizer
Nagurka, Mark	Marquette University

Pastel, Michelle	Corning
Pistikopoulos, Efstratios	Texas A&M Univ
Polsky, Yaron	Oak Ridge National Laboratory (ORNL)
Ramasubramanian, Ram	Clemson University
Ramsey, Doug	Alcoa
Reed, Wayne	Tulane
Reklaitis, Rex	Purdue University
Rinker, Mike	Pacific Northwest National Laboratory (PNNL)
Saldana, Chris	Georgia Tech
Samad, Tariq	Honeywell
Samotyj, Marek	Electric Power Research Institute (EPRI)
Shankar, Ravi	Dow Chemical
Shi, Jan	Georgia Tech
Shinbara, Tim	MT Connect
Swink, Denise	SMLC
Taylor, Rebecca	National Center for Manufacturing Sciences (NCMS)
Tilbury, Dawn	University of Michigan
Tran, Julie	SMLC
Westmoreland, Phil	North Carolina State University (NCSU)
Ydstie, Erik	Carnegie Mellon University (CMU)

Appendix II. Breakout Session 1– Smart Manufacturing Semantics

Question 1: What are crisp definitions/meanings that capture the semantics of advanced manufacturing: Sensing, Control, Automation, Platform, Visualization, Informatics, Digital Thread, Design vs. Operations, Life Cycle, Model Integration

Question 2: What are key attributes that define Smart Manufacturing vs. Digital Manufacturing?

Question 3: What modeling, data and infrastructure elements overlap and/or intersect?

Group 1 Notes

Question 1: *What are crisp definitions/meanings that capture semantics of advanced manufacturing: sensing, control, automation, platform, visualization, informatics, digital thread, design versus operations, life cycle, model integration?*

Aggregate definition

- Difficult to come up with specific standard definition
  - Industry-dependent (aerospace, automotive, chemical, pharmaceutical,…)
  - Discrete/continuous production dependent
- PCAST definition
  - Family of activities that (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.
- Definition attempts:
  - Use of digital data for optimizing manufacturing processes
  - Uses complementary power of data, models, material, optimization, control and infrastructure to achieve a step change in current paradigm

Piecewise-definition: advanced = all, conventional = some

- Sensing:
  - Definition: measurement, hard and soft sensing (low-level data)
  - Needs: reliable, low-cost, calibration-free sensing technologies
- Control:
  - Definition: action based on measurements
  - Needs: reliability, user-friendly control interfaces
- Automation:
  - Definition: replacing manual tasks
  - Needs: low-cost, multi-functional automation technologies
- Platform:
  - Definition: software (computing architecture, applications) and hardware that enable cross-enterprise sensing, control, automation
  - Needs: open-source, interoperability, standard interfaces, integration
- Visualization:
  - Definition: enabling display of process and product data
  - Need: approachable GUI interfaces for users
- Informatics:
  - Definition and needs: data mining, analytics

- Digital thread:
  - Definition: data pertaining to design – manufacturing – end of use – EOL (or digital tapestry according to LM)
  - Needs: information traceability, security

- Design versus operations
  - Definition: product specification data, manufacturing processing data
  - Need: seamless integration of data
- Life cycle
  - Definition: resource consumption and waste generation in processing
  - Need: integrated LCA in production for consumers, planning tools for industry for transitioning small scale discovery to large scale production
- Model integration
  - Definition and need: individual machine models (component) and end-to-end system models (aggregate)

Group 2 Notes

Definitions for Advanced Manufacturing (AM)

One participant said, "I know AM when I see it", another said "AM is in the eye of the beholder". There were many definitions of AM that were proposed, the common thread being almost anything that makes manufacturing more efficient than before. After a while, what was AM at first becomes routine.

Some of the definitions of AM proposed:

- AM is anything that improves the continuum of interests in the manufacturing sector. AM is wherever a process could be improved, higher precision achieved, new materials produced

- AM depends on the historical era, it has been talked about for many years, at least 30. From manufacturing side the definition hasn't changed much in 30 years but the technologies have changed

- AM concerns automation, robotics. AM involves process optimization, reduction of rate limiting steps, e.g. manual sampling

- AM involves no-touch manufacturing, which is flexible, creating higher level skills, at whatever levels are needed.

- AM involves producing things you couldn't otherwise produce; e.g. For *in situ* microstructure, multidisciplinary technologies brought together at state of the art, to deploy a system that couldn't be done with a traditional process

- AM ensures scale up and reproducibility. E.g. Boeing wants to make a composite-based plane. They had to put together varying technologies to make what they couldn't make before

- AM means minimizing capital/time needed to re-organize for new manufacturing capability. It can provide a way to automate your recipe

- "Advanced" is a relative term, not an absolute term
  APC=advanced process control

- A technique in 2000 that was APC, does it graduate out of the category.

- It's really the ability to measure and have more control over manufacturing

- There is not a single sufficient term that defines Advanced Manufacturing

- The level of human supervision is reduced; the moment one has plug and play, one is at the AM level.

- AM is whatever yields improvements in efficiency, productivity, profit by way of using data algorithms, etc.

- What Advanced Manufacturing is <u>NOT</u>: Where the process is well understood and has been implemented.

Differentiate 'Smart Manufacturing' (SM) and 'Digital Manufacturing' (DM)

- The origin of DM is in the CAD community, in digital representation of objects and their subsequent manufacture. Growing from the mechanical and industrial engineering community it has become quite sophisticated and is often referred to as 'Digital thread' or 'digital tapestry', whose use is especially prominent in the defense and aerospace industries.
- DM allows, for example simulations of devices and processes, before carrying them out physically; e.g. CNC making objects in virtual form through to assembly. DM is technical and about actual manufacturing, not about management aspects. There are legacy notions of DM, which should be preserved and are taken from the communities in which they are operative, MEIE, DoD. Started from the CAD community

The question arose: Is DM object-oriented? (e.g., designing and building a specific molecule) What about computer assisted materials design? Is that part of it?

- SM has been described as more 'visionary' and 'philosophical' than DM as it makes informed, model based decisions, etc., whereas DM is technical and does not refer to broad industrially important factors such as supply/demand, geography, transportation, market conditions, etc. Enterprise decision making based on local, national and global market conditions, materials logistics, supply chain
- SM is a philosophical or visionary system concerned with model based decision making that impacts all aspects of manufacturing –market, supply chain, safety, downtime of machines, logistics, profit , design, processes, production, etc. - DM, concerned with technical representations and manufacturing, is one of the engineering tools available to SM to carry out these tasks.

- An important outcome of SM is agility, sustainability, and quality for a manufacturing operation to adapt quickly (e.g., a hurricane is coming; ramp up roofing manufacturing and distribution).

- SM moves more towards model-based vs human experience decision making. Having a model at the basis is less dependent on specific people; SM seeks more autonomous decision making to deliver agile, sustainable, high quality products.

- SM involves, Data, information, knowledge, leading to smart, robust decisions and robust models that connect inputs to outputs

Smart Manufacturing Definition #1
Smart Manufacturing is an enterprise wide, dynamic, model based, decision making system for all aspects of manufacturing operations, which leads to optimization of agility, sustainability, and quality. It takes copious and diverse data to produce information from which knowledge is forged to make robust decisions.

Smart Manufacturing Definition #2
Smart Manufacturing is about Data->Information->Knowledge-> Wisdom (DIKW). It uses advanced sensors to collect data. Data and models provide real-time information. Information is then used to run the manufacturing plants better and generate knowledge (e.g. reduce energy use, improve quality, agility, improve productivity, improve sustainability, etc.). When knowledge is used across enterprise, this is where we have Smart Manufacturing and Wisdom.

There are several good google definitions of SM also:

- SM is at an enterprise level; e.g., make widgets even when market has crashed, but in SM you know rate of production needed to meet market; integration of market, supply chain, and manufacturing measures

Why do we need to distinguish DM and SM? SM more of a chemical engineering side. MEIE (Mechanical Engineering/ Industrial Engineering) more from DM side (e.g. CNC making object in virtual form through to assembly).

SM is less about business decisions, rather how to manage marketing, sales force, etc. if say two machines go down, back orders, capacities, etc.
SM is an overarching platform, directing advanced manufacturing, under which DM is operative

Group 3 Notes

What are the crisp definitions/meanings that capture the semantics of advanced manufacturing: Sensing, Control, Automation, Platform, Visualization, Informatics, Digital Thread, Design Vs. Operations, Life Cycle, Model Integration

Sensors

- Transducers, intelligence, self-awareness, connectivity, monitor state of manufacturing, (NOI definitions).
- Should include soft sensing; but data from higher level systems may not fit the soft sensor category

- Sensing vs advanced sensing – sensing is a state. Going beyond, providing context becomes advanced. Parameterization gives you more
- State of the system = sensor. Physical state = sensor.
- RFID is a sensor. Context and communication makes it smart. Today it requires a team to put together a sensor on a machine. Need easier ways of plug and play. Self-configuration, self-awareness, automatic calibration, reporting of malfunction
- Tell when sensor is not functioning – advanced capability
- Communication protocols that allow information to be available on a cell phone for example – advanced
- Is a phone a sensor, or bunch of sensors
- Security and reliability awareness – means smart
- Sensing above the physical state is a sensor? No.
- Multiple measurements by a single sensor – this is advanced as well.
- Networking sensors = may not be physical, but still measures.

Control

- Manipulate the state based on data
- Actuation, measurement vs control
- Focus is more process control (discrete, continuous). But still can have multiple levels of definition. Physical state, all the way up to enterprise, at different time scales. Algorithms, asking someone to take action, to maintain process to a target (stability, performance are part of that).
- Control – needs to have sensor, target and an actuator (could be valve, human, etc)
- What is advanced control? Models, optimization, dynamic/adaptive, predictive (all at various levels of the manufacturing
- Is control local or shared? Shared makes it advanced, and a broader sense
- Automation
- Encompasses everything, too broad
- Is integration part of automation? Automation = repetitive?
- Right information to make decision is part of automation

What about monitoring?

Platform

- Same fabricating environment/infrastructure could mean platform
- But here we mean platform as being something that connects the enterprise. Standardization becomes part of it
- Providing tools is part of platform?
- Enables connectivity
- Platform = infrastructure and tools to develop and deploy
- Underpinning that allows you to connect consistent things together
- Platforms could connect suppliers as well
- Platforms enable toolkits to connect
- Common set of rules, protocols that allow different products, elements etc. to work together. Needs to be open.
- Platform is enabler for smart manufacturing
- Expansion, plug and play, interoperability, are all characteristics of platform
- Platform brings information, applications and humans, machines etc. together
- Platform is middle ware
- Provides protocols
- Hardware needs to be part of the platform – e.g., interconnects, communications

- What is the bus structure for manufacturing platform, so hardware + software
- Platform – architecture/framework
- Platforms vs standard platforms
- Need to define what platform characteristics need to be

Visualization

- Intended for human user.
- Present right information to right user in the right form at the right time = smart
- Display of information in the right context
- Visualization is limiting: how about sound/audio?
- DMDI – visualization includes taking information/computational data that human can visualize to make decisions on. Information from multiple sources, sensors, then presenting it in a visual manner
- Visualization turns data into information
- Visualization is one form of presentation
- Utility industry – enormous amount of information is visualized.
- "Presentation" is a better word than visualization

Informatics

- What you do with information
- Data analysis
- Transformation aggregation, processing, etc. before visualization is done
- Different than platform. Informatics is more about processing.

Digital thread

- Collection of data from initial creation of product through disposal or reuse
- Digital tapestry, digital quilt
- Data from product design through manufacturing
- Systems will have multiple threads
- Focus on ability, not how exactly to do it
- There is manual translation today in many places
- Any user in the life cycle can consume the data across the enterprise. All the way from concept to re-user (including requirements)
- Birth certificate to death certificate, genealogy, pedigree, are other words, traceability, forensics
- Documentation is part of it
- Pedigree should include materials, not just product
- Where do we draw the line on how far to go (what electricity it used, where it came from, etc.) Needs to be in context of the application or product.
- Needs to be system not just product or process

Design vs operation

- Being more integrated
- Operation makes it – how to do that is design.
- Design has to come before operations, but there is more concurrency these days
- Design for manufacturing – brings these two together – including optimization, iterative
- Transformers

Life cycle

- Birth to death, cradle to cradle (recycle),
- Going back all the way to the customer need?
- Who made it, who ordered it, how it was made
- Design has lifecycle itself. Life cycle for manufacturing could include original source? Or how much CO_2 was taken up? Total balance of energy? Repair is part of lifecycle

Model integration
- Need to define what "Model" means here
- Design models, process models, data models
- Model integration into control, model integration into inspection
- Need taxonomy of models to define further
- Data is shareable between models
- Integration of process and manufacturing models
- Collaboration of models that are used to make decisions
- Feedback loops between models
- Integration of metallurgical to thermomechanical models
- Models of what you are making vs models of the equipment that is making it
- (goes back to common platform)

What are the key attributes that define Smart Manufacturing vs. Digital Manufacturing?
- Digital data from concept to manufacture – use it intelligently – process, product, data – cannot distinguish between digital and smart
- Digital comes down from design to manufacture, Smart comes from bottoms up – need to intersect
- Digitalization is vehicle to making smart, analysis to make it smart, business vs digitalization capability
- Information generated at design, share it through manufacturing and life cycle. Connect silos of optimization and connect them together, be smarter about how you connect and integrate to make it smart manufacturing. Intelligent machines, analysis using process/product data are all smart manufacturing
- AMP 2.0 – if institutes are directionally correct, don't change course. What are the additional technologies that need to be invested in? How do we get Menlo Park to think like Detroit? No clear separation when we started (between DM and SM). Smart = common standards of practices that allow more people to be part of the manufacturing – open platforms, higher marketplace level.
- DMDI project calls cover a lot of SM technologies
- Should focus on NSF TRL 1-3 to delineate and define. NNMI is a network so the institutes can coexist
- Robot vacuum cleaner is smart, not necessarily digital. Self-aware is smart.
- DMDI is not attacking the big data problem or controls,
- Difficulty to understand documents – could substitute DMDI and SMI. 95% overlap – standardization, interoperability, cyber security are all part of DMDI as well. Reporting form sensor level up, big data, real-time simulation/control. Smart and intelligent are words used interchangeably. Need to make clear distinction between the charters of the two institutes.
- Beneficial to see the documents on 13 areas that we are investing in. DMDI will have overlap with a lot of areas. What are the things that have not been taken care of?
- NSF workshop: what is the fundamental work that needs to be done?
- In DMDI some areas were not being covered: more companies in eco system, energy initiatives, more about the manufacturing process than product, less about the technology more about the business/marketplace.
- Can we bring this in perspective from product vs process industries? But one of the targets here is NOT to separate these.
- DMDI does not consider all systems engineering aspects – look at entire manufacturing as a whole. This is an area that is not being worked on but is in the vision of DMDI
- TRL 1-3 is not necessarily included in the institutes – NSF workshop needs to focus on that
- AMP discussion was more focused on the sensing, control technologies, etc.

- If we wait until DMDI is done to figure out what's missing, it would be too late
- [NSF w/s – capabilities that are building blocks of the institutes]

What modeling, data and infrastructure elements overlap and/or intersect?
- (already discussed in above questions)
- Platform for model integration – for the whole enterprise, especially for small manufacturers
- Creating meta models, seamless links
- Verification and validation of models should be considered
- At what levels are we considering models? Product, process, wrappers, platform, interconnections
- Multi-physics modeling – modeling languages that allow you to connect from models from diverse domains
- Data analytics also need models

Group 4 Notes

Q1: Sensing: accurate translating 'physical' into 'digital' information

- **Control:** intelligent transformation of information into 'actions' (towards objectives or to achieve desired objectives)

- **Automation**: process to deliver actions without (or with supervisory) human intervention towards product/process performance

- **Platform**: interoperable/secured/reliable standardized infrastructures (software + hardware) including computing systems - for legacy and new software/hardware

- **Visualization:** graphical tools for human decision making

- **Informatics:** extracting intelligence out of smart information

- **Digital Thread:** Uniform underlying structure (following product life cycle)

- **Design vs. Operation**: integrating the creation of process/products with operational feedback for continuous improvements

- **Lifecycle**: compilation of all process/product steps from inception to supply-chain through end-of-life information (supplied by digital thread)

- **Model Integration:** creating open modelling environments with ability to connect, be deployable, scale-able, interoperable, and supporting all other activities

Q2:

Smart Manufacturing Key Attributes:

(i) enterprise-wide and factory
(ii) continuous and/or discrete and batch
(iii) digital and analog communication
(iv) legacy manufacturing
(v) closed-loop integration for continuous improvements and optimization
(vi) decision-centric
(vii) plant floor level through R&D

Digital manufacturing Key Attributes:

(i) end-to-end digital thread
(ii) discrete focus
(iii) focus on new processes/products
(iv) integration of information and intelligence in digital form
(v) life-cycle aspect from design to manufacturing and support
(vi) right first time and faster

Q3: Modelling, data and infrastructure - Overlap and intersect: product, optimization, performance metrics and relationships, data analytics and visualization, process models (adaptive), computational tools, common activities and people, across organization

Appendix III: Breakout Session 2 – Fundamental Research Needs for ASCPM

Breakouts organized by (S) sensors and monitoring; (C) controls and processes; (P) platforms and standards; and (SC) supply chains and scheduling.

Question 1: What are the key fundamental research challenges in each area, and how do they relate to different manufacturing and enterprise structures – continuous, batch and discrete (building off AMP 2.0 workgroup summaries)?

Question 2: What roles do models play in addressing research challenges?

Question 3: What are the needs in visualization and data informatics in each area?

Question 4: How do research needs impact platform infrastructure requirements?

Sensors and Monitoring Group

- AMP 2.0 Technical gaps. Sensors, non-invasive sensing, real-time process analysis, wireless connectivity, smart sensors, managing sensor uncertainty, standards for sensing calibration
- What are key challenges? Process monitoring for unsteady systems, robust models across scales, sensor placement, soft sensing in case of uncertainty, sensor uncertainty to improve models, sensor data to improve models, model maintenance, and quantification of uncertainty.
- Roles of models? Every point!
- Needs of visualization and informatics? Good GUI. Data compression for data. Big data challenges (large amounts, 2D 3D visualization, data security)
- Research needs for platform infrastructure? Not a research question. Needs standards but not basic research.

Summary Slides:

AMP2.0 – ASCPM Technical Gaps

Sensing and Measurement

Gap S-1: Sensors for bio-, nano-, and micro-manufacturing

Gap S-2: Non-invasive sensing and measurement solutions for advanced manufacturing

Gap S-3: Real-time process analyzers with multi-sensor data fusion capability

Gap S-4: Wireless connectivity and self-contained power delivery/harvesting

Gap S-5: Knowledge-embedded smart sensor systems

Gap S-6: Methods for managing sensor data uncertainty

Gap S-7: Standards for sensor calibration and measurement

Question 1: What are the key fundamental research challenges in each area, and how do they relate to different manufacturing and enterprise structures – continuous, batch and discrete (building off AMP 2.0 workgroup summaries)?

- How to design process monitoring systems for unsteady conditions (e.g., startup conditions and product transition/change over, process shutdown)
- How to develop models that are robust for all scales (e.g., pilot to large-scale manufacturing)
- How to optimize sensor placement to improve process monitoring performance
- How to use easy-to-obtain sensor data to infer important unmeasured variables that are difficult to measure, for systems with uncertain models and sensors
- How to deal with sensor uncertainty and use the information to improve model quality
- How to use sensor data to better infer first principles (e.g., reaction kinetics) and connect to the physics
- Model maintenance issue: when to update model and how to update model?
- Quantification of risk/uncertainty in model predictions

Question 2: What roles do models play in addressing research challenges?

- Everywhere! See question 1

Question 4: How do research needs impact platform infrastructure requirements?

- Important but not research question
  - Standard and protocol
  - Good visualization
  - Effective way to track all kinds of data
- Secured Cloud based computing platform for remote use

Question 3: What are the needs in visualization and data informatics in each area?

- User friendly: good GUI. Different requirements from operators to scientists
- efficient data compression and wireless transmission technology for large data set (e.g., video image)
- Big Data:
  - Typical chemical plant measures 10,000+ variables, how to effectively visualize and present these variables for different users for better decision making
  - Translate 2-D process flowsheet into 3-D drawing for more effective troubleshooting by plant operators
  - Data security issues

Controls and Processes Group

- New Gaps: Large-scale hierarchical distributed and complex, extending from 1D to 2D to 3D, unstructured information, correctness verification, clarity and resilience.
- Top 5 Gaps: Large-scale hierarchical (12 votes), high fidelity modeling for control and optimization (11 votes), theory and control of difficult (nonlinear, stochastic, hybrid) systems (7 votes), control and planning (7 votes), and unstructured information (6 votes).
- Bridge the gap between scheduling and control.

Summary Slides:

Controls and Processes:
Fundamental Research Needs

1

Annex 2: Transformative Manufacturing Technology: Technical Gap Assessment in Control and Optimization

- C-1: Theory and algorithms for control of fault-tolerant, stochastic, nonlinear, hybrid systems
- C-2: Smart diagnostics, prognostics, and maintenance
- C-3: Human-in-the-loop monitoring and control
- C-4: Advanced control for discrete manufacturing
- C-5: High-fidelity modeling and simulation for control and optimization
- C-6: Integration of process control with planning and scheduling
- C-7: Optimized co-design of process and sensing/control strategy
- C-8: Energy optimization with microgrids, smart grids, and cogeneration

2

New gaps identified

- C-9: Large-scale, hierarchical distributed and complex systems
  - With simple controllers
  - Close the loop at the enterprise level
- C-10: Extending control from 1D→2D→3D
  - We are good at 1D trajectory generation and tracking
  - How can we find inverse solutions to shape creation
  - Coupling design with control
- C-11: Incorporating unstructured information
  - Crowd-sourcing, video, audio, ...
  - Integration of multiple data streams
- C-12: Correctness verification
  - Security and resilience

What are the top 5 gaps?

- C-9: Large-scale, hierarchical distributed and complex systems (12 votes)
- C-5: High-fidelity modeling and simulation for control and optimization (11 votes)
- C-1: Theory and algorithms for control of fault-tolerant, stochastic, nonlinear, hybrid systems (7 votes)
- C-6: Integration of process control with planning and scheduling (7 votes)
- C-11: Incorporating unstructured information (6 votes)
- What role do Models play?
- What are Visualization and Data Informatics needs?

C-9: Large-scale, hierarchical distributed and complex systems

- How to design simple and robust controllers for these complex systems?
- Can we close the loop at the enterprise level?
- When should the control be decentralized vs. decentralized?
  - Analyze the complexity
- Models used to capture emergent behavior

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C-5: High-fidelity modeling and simulation for control and optimization

- The integration of high-fidelity models and simulation within real-time control and optimization algorithms has long been a futuristic vision. Advances in high-performance computing and other information technology developments promise to make the vision a realizable proposition for significant-scale manufacturing problems in the now-foreseeable future. Modeling underpins virtually all advanced control and optimization capabilities.
- *This is a high-priority gap that can be bridged in the medium-to-long term.*

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C-5: High-fidelity modeling and simulation for control and optimization

- Faster than real-time simulation
  - Predictive simulations, "what-if" analyses
  - Visualization of potential outcomes
- Uncertainty modeling and quantification
- Models at multiple levels of fidelity
- Complexity across multiple scales in time and space
- Developing interfaces between models
- E.g.: Weather prediction used for chemical/power production

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C-1: Theory and algorithms for control of fault-tolerant, stochastic, nonlinear, hybrid systems

- There is a dearth of mathematical theory and computational implementations thereof that are sufficiently flexible and robust to deal with the complex nature of manufacturing plants and processes. Specific aspects of this complexity that must be considered include uncertainty, tolerance to equipment failures, and nonlinear and hybrid dynamics. There is a long history of research in control theory but the manufacturing domain has not in general been a target for this research. Continuous as well as hybrid discrete/continuous manufacturing processes will benefit if this gap is bridged.
- *This is a high-priority gap with potential impact on U.S. manufacturing over the medium-to- long-term horizon. Addressing this gap will require focusing on the manufacturing domain and involving manufacturing experts in addition to control theorists.*

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C-1: Theory and algorithms for control of fault-tolerant, stochastic, nonlinear, hybrid systems

- Develop new control theory (and extend existing) for manufacturing system challenges
  - Model-based control, model reduction for control design
- Incorporate uncertainty (e.g. in incoming material)
  - Modeling uncertainty and complexity
- Used widely in continuous process
  - Not as widely in discrete manufacturing
- First principles + Statistical models

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C-6: Integration of process control with planning and scheduling

- As a result of the different temporal and spatial scales involved in planning, scheduling, and control in manufacturing facilities, different and compartmentalized tools are typically used for these critical functions. More seamless integration would enable factory operation at closer to the true optimum, greater agility in response to plant and market conditions, and other benefits. This gap is evident across the manufacturing spectrum, including for discrete manufacturing.
- *This is a high-priority gap. Recent developments have shortened its horizon to the short-to- medium term.*

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C-6: Integration of process control with planning and scheduling

- Downstream adaptation to upstream conditions/results
- Tradeoffs between quality and throughput
- In process industry, these are two different communities
  - They use different models
  - Need to bridge the gap between frameworks
  - Ensure consistency

11

C-11: Incorporating unstructured information

- How can the large volumes of newly-available, unstructured data be leveraged for control and optimization?
  - Audio & video streams of process
  - Crowd-sourcing (e.g. traffic patterns)
- Can some of this data be used to build models and design the controller?
  - Classification of which data is useful
    - Visualization of these data streams
  - Integration of multiple data streams via models
  - Soft/virtual sensing

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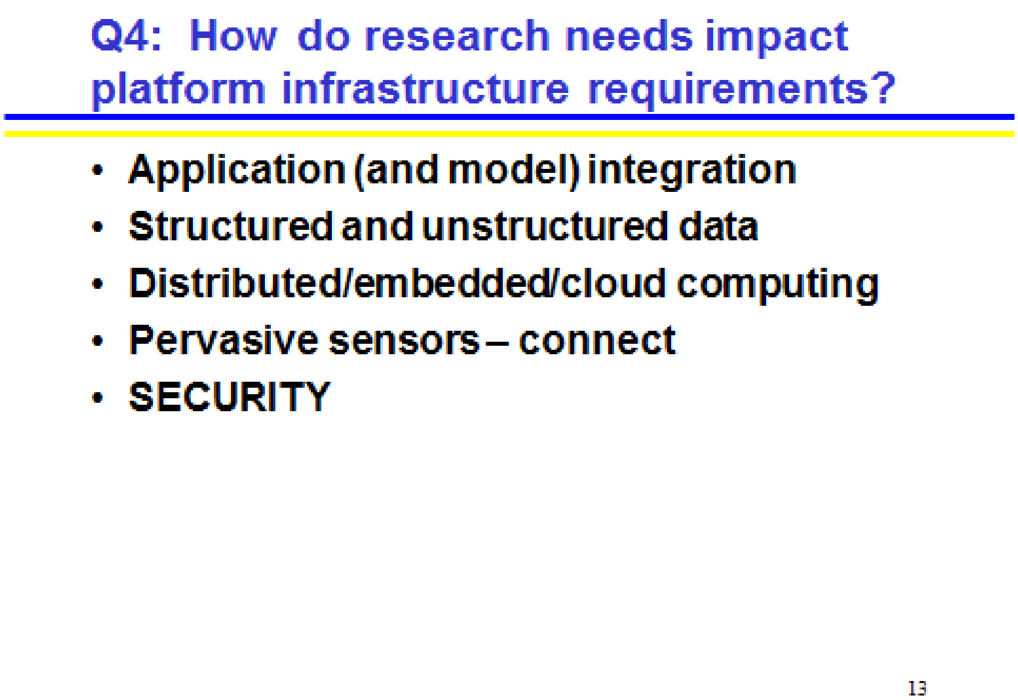


Supply Chain and Scheduling Group

- Account for uncertainty in operations. Can we use historical data for developing uncertainty models? Can we verify solutions under uncertainty? Can we incorporate cost variability into scheduling?
- Federated models for design, control, and operations.
- Optimal sensor placement/design.
- Smart sensors and dealing with data.
- Data modeling. Historian and predictive systems.
- Enable tying models to data.
- Computing and hardware to allow scalability.
- Interoperability and compatibility. Support coordinated decisions between entities.
- Platform should be easy to deploy, easy to integrate, easy to extend, with security, including visualization, support SME.

Summary Slides:

Q1: What are key fundamental research challenges in SCS?

- Lack of formal models for discrete manufacturing facilities
- Lack of performance in solving the scheduling models that are currently available for (ever) large(r) scale systems. Solution techniques still do not scale well
- Inconsistencies between different decision-making levels in continuous processes. How can information be aggregated, disaggregated and propagated across different levels/time scales. E.g., data are used to update model at a lower level, how can this model be propagated up the decision-making hierarchy.
- How can data be used to make sure a model reflects reality in the best way.
- Uncertainty in continuous manufacturing: how can uncertainty be accounted for in process operations. There is also uncertainty in the supply chain (for example, delayed deliveries can upset the operation of an entire manufacturing facility).
- Can historical data be used to build better models of uncertainty?
- Can the quality of solutions under uncertainty be verified?
- How can energy costs/variability in pricing be connected into production scheduling scenarios?
  - High frequency variability must be reflected in calculations that account for a much longer time scale (e.g. 5 minute variability in energy prices to be accounted for in week-long scheduling calculations).

Q2: What roles do models play in addressing research challenges?

- **Research challenge for process industries:** Federated models that are a ***single source of truth*** for design, control and operations
- optimal sensor and actuator network design for nonlinear and discrete manufacturing systems (e.g., expand the work done in the past, concerning measuring flows, to measuring properties)
- modeling and visualizing the evolution of IT network infrastructure (the other half of cyberphysical systems) in a complex (discrete) manufacturing environment. E.g., in a smart factory, when you put a new machine on the floor, it will appear as a resource in the manufacturing system and the data communication to this machine must be described effectively. The research challenge is around ontologies and representation languages.
- Data historian and predictive systems are disconnected. The data structures and the database, query software are incompatible. Comparing past planning with current data is difficult; interactions/ reconciliation require significant human intervention/effort. Creating feedback actions in scheduling (re-scheduling, schedule repair) is difficult. This connectivity issue should disappear in a smart manufacturing environment.
- **(this ties directly to the previous point!)** *break traditional hierarchical structure of the decision-making activities in a process, and connect the production layers (e.g., scheduling) with the control layers. What is the trigger for rescheduling/plan repairs??*

Q3: What are the needs in visualization and data informatics?

- using historical data as an "informed prior" for decision making.
- **For complex systems:** How can the CURRENT state of the system be presented to an expert-level user who can evaluate the operating status (ok/not ok) the process ? How can we create "situational awareness?" What is the best operator interface? Can data be used to generate alarms which increase situational awareness? Can alarm management be implemented to indicate root cause of the problem?
- Is there a general approach to visualization, which is effective independently of the "data richness" of the environment where it is applied?
- **Research challenges:** Study the effective interaction between human factors research, control and scheduling.
- (along the same lines) Interactive visualization of time series data as well as supply chain/ scheduling (e.g., going "beyond the Gantt chart"). Study scenarios. This can support better decision making in the absence of an optimization-based system, as well as multi-stakeholder decisions.

Q4: How do research needs impact platform infrastructure requirements?

- Tying models to data (selecting data, developing ontology for seamlessly defining and establishing this connection).
- Support parallelization, scalable computing, dynamic allocation of hardware resources
- **I**nteroperability and compatibility, enable communication between separate organizations, not just between business entities within the same organization**.**
- platform should help make coordinated decisions between separate entities that are accessing the same resource (e.g., air separation plant inside a steel plant, both use electricity, what is the "common good" for the two organizations?).
- platform infrastructure should be easily deployable and new implementations should easily integrate in existing system
- information and data security must be intrinsically built in the platform. Appropriate encryption levels must be built in.
- platform should support and enable visualization.
- platform should be computationally parsimonious (especially for small/medium enterprises)

Platforms and Standards Group

- AMP 2.0 Gaps. IT Infrastructure for sensing and data.
- Platform – Enterprise integration and optimization for distributed control, including data and scaled infrastructure.
- Place to connect hardware, software, people. Rules and standards. Analytics, modeling, simulation, metrics.
- Open – Open access applications, open market, open community, validation, proprietary and non-proprietary. Open architecture, standards based, vendor agnostic, open stack model.
- Integration of sensing and data systems. Want to reduce cycle times.
- Integration of sensing and data – ISA 95. Legacy machines. Predictability, reliability, robustness of wireless sensing.
- Gaps in modeling. Needs intuitive level of abstraction. Interactive platform (like gaming). Model the business, transportation, resource consumption. HIL modeling and conflict resolution. How to model, right level, scaling of model.
- Security – malware, firewall, SME, peer-to-peer, attack detection.

Summary Slides:

AMP 2.0 Gaps

- Gap 1- IT Infrastructure that facilitates enterprise wide (1) integration of sensing, data and systems, (2) orchestration across heterogeneous systems, (3) management of public and private data
- Gap 2 – Standardized data models and information semantics
- Gap 3 – Infrastructure that increasing extensiveness
- Gap 4 – As complexity of platform integration grows – methods to build platform infrastructure
- Gap 5 – Information, data and IP security

Platform

- Platform (foundation)
  - Enterprise integration and optimization (distributed control)
  - Data
  - Scaled infrastructure
- Place to interconnect H/W, S/W and people
  - Software application & data schemas infrastructure
  - Rules and standards for interconnecting in deployable form - enabler
  - Actionable (to accomplish goals) – analytics, modeling & simulation – metrics
- Open Platform – Industry Driven
  - Open access applications – marketplace open source, community source, commercial – still managed, mediated, certified
  - Data managed for manufacturers to support applications about applications
  - Open architecture platform – standards based architecture - vendor agnostic – its own H/W and S/W - Open Stack (model)

Gaps & Research Areas

Integration of Sensing and Data Systems - For rapid application of data to address customer requirements and reduce cycle times

- ISA 95
  - Need to integrate through layers
  - Need to rethink ISA 95 model
- Reduce latency and open data rates so that a platform can be used for multiple machines and be effective for operational inter when farther removed – supply chain
  - Separate single data flows from bidirectional data flows
  - Methods to deal with bi-directional flows - synchronicity
- Methods to balance local and distributed opportunities
- Methods to retrofit legacy machines with sensor and data systems
- Predictability, reliability, robustness/ruggedness of wireless sensors

Gaps & Research Areas

Orchestration Across Heterogeneous Environments (standards)

- Methods to deal with disparate data types
  - Continuous, discrete, human in the loop
- Methods to normalize and contextualized disparate data types
- What are the right things to measure for the right decision
- Sensor calibration – self assurance of right measurement
- Data quality/ integrity; authenticity of data
- Resiliency of the data-model function
  - State, self awareness, self diagnosis and healing
- Authorization for device, senor and human data sources

Modeling Gaps

- Intuitive level of abstraction
- Interactive platform (gaming)
  - Modeling impact of the platform
  - Modeling with different kinds of models
  - Model the business, transportation, resource consumption
  - Human in the loop modeling and conflict resolutions
  - Using the platform to model forms a model; using this model
- How to model
  - Right level of model
  - Scaling broad-based

Security Gaps

- No connectivity still the first solution – study risks
  - Study malware, firewall impacts on network solutions – risk vs. benefit
  - Study platform security vs. small company security, peer to peer solutions
  - Study security attack detection in networked systems vs. not

Appendix IV: Panel: Observations on Research Needs (Industrial/Academic Panel)

Question 1: What are key unmet long-range R & D needs? (industry & academic panel)

Question 2: What are the fundamental research components that can be integrated with industrial practice?

Panel Session Summary

Interactive Panel Discussion with the following panel members:

Doug Kushnerick - ExxonMobil
Rex Reklaitis - Purdue
Alison Gotkin - UTRC
Shiv Kapor - UIUC
Chad Farshman - Corning
Eric Ydstie - CMU
Bryan Dodd - GE

Doug – Molecule Management and Plant Automation groups. Don Bartusiak control systems lookout document forthcoming. Plug-and-play, interoperable requirements. Strong internal debate over models, use, and accuracy. Simplification is key. For a task, if you don't have to do it, you can't do it wrong.

Rex – Sensing was interesting. New measurements provide new information. Calibration, maintenance of sensing are still issues. System does not really learn from mistakes currently, just deals a bit with uncertainty. Need people in algorithms to really improve computation rather than use canned software. Not much on fault monitoring and diagnosis. Supply chain problem is integration with actual data sources.

Alison – Business development manager. Helicopters, engines, HVAC, elevators, etc. Any solution must be affordable. Metrics like energy and quality must be demonstrable. Dealing with proprietary manufacturing lines. Policy to force people to use platform? Develop simple systems at operator level, not requiring a PhD.

Shiv – Background in machining and modeling. Modeling is a key for smart manufacturing. Models must be simple and accurate but also deal with uncertainty. Limited discussion on health monitoring and maintenance. Communication and data streaming areas are important but manufacturing has dirty data. Model integration infrastructure requires out-of-the-box thinking. Plug-and-play infrastructure.

Chad - Manufacturing and decision support. Software cannot handle uncertainty. Scheduling with uncertainty is a big deal. Unstructured information like video inputs. Flow of solids is limited. Measuring aesthetics and other unstructured measurements.

Eric – Controls. Physics plays a major role. Control of batch processes for Dow Agro. Quick control with limited models, close to optimal, easily. Form, shape, color, feel measurements. Code verification problems to implement verifiable solutions. Distributed system solved dynamically potentially.

Bryan – Brilliant factory for connectivity. Ubiquitous computing. Issues of verification of models and change on the fly. What is the testbed going to be? Implementation issues. Control and optimization is still a big issue. System degradation and sensor degradation.

Doug – Benchmark problems have issues.

Alison – Sophisticated manufacturing capabilities are available.

Doug – Workforce is an issue. Built around current products, get tied down.

Shiv – Need to use models for control and business actions.

Doug – They use soft sensing in plant systems.

Eric – Systems Engineering Masters at GT. Use different software to solve problems.

Bryan – Students have an opportunity to make a difference in business.

Doug – Hire good people with strong math skills.

Alison – New power electronics / controls group.

Westmorland- Gap between machining / discrete manufacturing and process manufacturing.

Bryan – May be able to go to distributed computer support for manufacturing.

Rex – NSF ERC is designed to pull together disciplines.

Burka – Multidisciplinary is hard to support and fund without an act of congress.

Appendix V: Breakout Session 3–Other Dimensions of Near and Long-range R & D Opportunities

Question 1: What are the potential impacts of ASCPM R & D on energy efficiency/carbon emissions, environment and safety?

Question 2: What are compelling industrial vignettes for ASCPM successes?

Question 3: What are the sensor, control, platform and software barriers to achieving success?

Question 4: What Apps could be broadly used for ASCPM?

Session 3 Summaries

Group 1 Summary
Q1 & Q3 – Smart Manufacturing must have a significant impact on many areas. Leads to better energy consumption, more efficient production, better regulatory compliance. Interaction with grid, cost of energy. Sensor refurbishment. IT issues. Need to use data.

Platform – connectivity and cloud access make applications easier. Remote monitoring and control possible. Data ownership becomes an issue.

Q2 – New paradigms requiring advance monitoring and control. Smart manufacturing enabled by new technologies. New designs and sensors. Service model allowing others to leverage capabilities.

Quality, reproducibility, sustainability, agility, schedulability.

Reference model to be used for various types of manufacturing scenarios.

Group 2 Summary
Q1 – ACEEE. Supply chain issues for efficiency. Scheduling of production to minimize costs. Adaptive controls may be useful. Tracking BTUs as dollars. Smart factory needs smart grid. Power storage and management may be needed. Safety is a key factor. Incentive / regulation can help move businesses to comply to standards. Health monitoring of device. Dollars to emissions.

Q2 – Monitoring of emissions. Cost of emissions.

Q3 – Business risk, cultural issues. Legacy issues. Issues dealing with change. Large enterprise, workforce issues, union issues.

Q4 – Limited results.

Group 3 Summary
Q1 – Dealing with scrap and recycle for energy. Variability / energy indicators. Startup and shutdown risks. How do we do continuous improvement in our process? Variable cost of electricity resulting in changes production.

Q2 – Hybrid car. Production supply chain.

Q3 – Security is a barrier. Sensor security could be a problem. PNP certification process? Design to operations with integrity checking, electronic supply chain issues and data management issues. Diagnostic interrogation.

Q4 – How do you develop a killer app for manufacturing? How do you engage crowd source development?

Group 4 Summary
Vignettes – Monitor recipe and make adjustment. Be more predictive. Discrete manufacturing doing measuring during production instead of final step. Adjust process during production.

Power Generation – forecasting models for demand and production adjustments. Food, forestry, metals, with variable material feed specs requiring adjustments in recipe.

May result in improved product quality. Less inspection. More consistent products. Better quality and less waste. Less variation of the product. Higher safety level. Less waste is lower impact and emissions.

Barriers- cost, availability of capital, justification for capital use, retrofit legacy equipment. Need better ways to evaluate the technology, like ROI. Need more technology in manufacturing. Lack of trained resources. Could use testbeds.

Closing Comments-

Eric – Energy systems for real-time use of electricity. Save money but waste energy. May still be green depending on use.

Group 1 Notes

Q1: What are the potential impacts of ASCPM R & D on energy efficiency/carbon emissions, environment and safety?

- Smart Manufacturing is EXPECTED to have a big impact on sustainability

- Applications

- Better energy consumption,
    - cheaper occupancy sensors, zone heating
- regulatory compliance (to track components of the production line),
- tie the energy pricing into production planning
- Managing demand and consumption; managing peak demand appropriately to manage costs
    - use renewables and alternative fuel
- machinery that is not performing at optimal efficiencies

- Grid Integration is a challenge: Onsite generation is a common occurrence at manufacturing facilities; net metering has a dependency on the utility - who is not incented to enable grid integration

Challenges:

- Lower energy costs are a disincentive for investment and ROI.
- Are we expecting the traditional manufacturing co's to instrument the sensors?
  - [Use the natural re-furbishing cycles to put these in.]
  - with the IT system and backend is challenging

Trends:

- cheaper connectivity, cloud solutions lowering the cost to infrastructure.
- Innovative financing models - no-risk/low-risk options from vendors/SMEs that allow manufacturers to opt in when ROI from sensor/EE investment doesn't meet their traditional hurdle rates

Platform:

Applications:

- cloud applications for analyzing consumption and automation
- Remote monitoring and control
- Concerns:
  - Concern about Data ownership if dependency on vendors;
  - Risk: Vendors adversely affecting production; conservative - product and competitive information privacy; Inertia
  - Cybersecurity - need to be able to go into lockdown mode

Profitability is crucial to viability

- installation of the sensors have to make the operation more profitable.

Q2: What are compelling industrial vignettes for ASCPM successes?

- Applications in NEW Paradigms where there are needs for remote monitoring and control
    - Biomass and renewables
- Capacity Management:
    - Improved utilization of plants
- Need agility in the plant
    - want to be able to reconfigure the spaces - can't compete in some markets.
- Additional TRENDS making a compelling case for SMART manufacturing:
- Things we know how to do but do them with more agility and nimbly? Needs acceleration of adoption of new technologies.
- UT is bringing manufacturing back to US for complex designs.
- Boeing when new designs are being taken up, they have to be done and have to be done using SMART techniques
- Enablement of SMEs to be able to match the smart manufacturing that the large manufacturers are able to support. (Job Creation)

- Is there a possible Service model for SMEs that the larger, or more advanced manufacturers can offer? Should the institutes focus on the enabling SMEs instead?
- Concept Example: Ability to take a CAD file and have multiple SME's/production facilities respond with quotes.

GOALS: quality, produce-ability, sustainability, agility, schedule-ability

- All the above 'ilities' are tied to getting collaboration between stakeholders
- Interoperable cad, sensors' application, manufacturing systems interfaces, schedulers
- Need to be able to capture the structure and a reference model so that RULES with above could be sent to a supercomputer to solve - could be a service for SME's.
- Job shop scheduling/Modeling opportunity:

Challenge:

- Applicability of Large manufacturers' models to smaller job shops is questionable.

Q3: What are the sensor, control, platform and software barriers to achieving success?

See response to Question 1

Q4: What Apps could be broadly used for ASCPM?

- Job shop scheduling apps
- Equipment maintenance applications
- Remote monitoring and control
- Enabler for applications - Capturing a reference model for manufacturing facilities (buildings have a BIM, integrated circuit representation has a semantic model)
    - enables a sandbox for applications to be built upon
    - data, storage, display, access standards
    - who are the best to lead this effort? - Government agency, manufacturing facilities, academics, other standards bodies?

Group 2 Notes

Q1. What are the potential impacts of ASCPM R&D on energy efficiency/carbon emissions, environment and safety?

International research reiterates that for carbon emissions, especially metals, not much is being addressed at machining. But 40% of the metal gets caught in the scrap. Could sensing reduce scrap and/or make it more recyclable?

- Increase metal part yield

Could scheduling reduce energy? Controls/sensing/optimization all come into pla

Explore and exploit interactions between various parts of the process. Ability to explore interactions can result in benefits. Everything is inter-related.

- For example, in air separation systems, if you do local optimization of one, wouldn't necessarily positively impact the other.

Identify process variability

- A metal manufacturer was casting as they always did; didn't notice that the amount of energy was significantly different and they discovered the feedstock had changed, but without info on energy consumption they wouldn't have found that out.

Energy use information as a KPI for inefficiency

Regenerative breaking on cars - are there examples in mfg? Harvesting waste heat?

Smart Manufacturing enables exploring synergies with the smart grid

Sync heat/power with supply grid; may have implications for energy efficiency for business drivers and environmental impact

High fidelity models can identify near miss types of scenarios – implications for safety.

Visualization tools can point to potential failures before they occur

Predictive maintenance and diagnosis

More embedded systems for safety – standards more pervasive in a system

Embedded sensing as part of your solution... Environmental play is that advancements can be embedded systems

Cohabitation (like robotics) – tactical vision -- but it needs to be more pervasive in all production systems. How can all production equipment safely operate as a system?

Safety by design in production; not an afterthought.

Safety is most difficult at start up and shut down – how do we get all the requirements in startup as part of procedures and work flow? Sometimes it's only in someone's head. Not maintained or updated if they are there; not consistently applied. Auto capture of best practices.

Alternative energy (methane at BMW for example) – is it a reliable energy source and is it dependable? It needs to be multiply sourced and managed well. Across sources and maybe providers. To extent can modulate energy use; manufacturing plant can be part of an energy resource

CA Duck Curve; future 20 yrs., net load in the system for the course of 24 hours in a day.

- If energy is "free" during day, how would your manufacturing change?
- If you can help deal with the net positive load; what can manufacturing do to absorb some of the variability?

Abundance of information; high levels of detail on energy consumption in manufacturing may give insight into how manufacturing uses energy which may be different than what we think today. There would be a way to spot trends; changes and revolutions

Convergence of infrastructure – water, transport, etc. Smart Manufacturing facilities should also be able to tell us about impact on water, use of water; transportation scheduling. For example, could you schedule workforce to manage road congestion

Group 3 Notes

Question 1: What are the potential impacts of ASCPM R&D on energy efficiency/carbon emissions, environmental and safety?

Question 2: What are compelling industrial vignettes for ASCPM successes?

Question 3: What are the sensor, control, platform and software barriers to achieving success?

Question 4: What Apps could be broadly used for ASCPM?

Vignettes/Applications/APPS

- Pharma
    - monitor recipe -> processes to guarantee product quality
    - Scalability of models
    - Digest actual mix versus recipe in real-time
- Chemical
    - Ability to predictive product (ensure quality aspects), versus end of line (off line) measurement, inferential/soft sensors
    - Take the variation out of the sampling
    - Less waste of resources
- Discrete
    - In process "CMM"
    - Measurement vs. after the fact
    - Low cost manufacturing by piece

- Power Generation
  - High fidelity models to predict weather patterns effects on demand needs
  - Ability to see forecasted rates to run industry -> from the power company
  - Oil price predictions
  - Energy savings
  - Lower consumer demand (I.E. power consumption)
- Food, Forestry, etc. (broadly represents most industries)
  - Ingredients from supply chain -> come with information needed for upstream recipe controls

Benefits

- Improved product quality with less waste/scrap and rework
- Reduction in time bringing new products to market (Product qualifications offline prior to disturbing the process)
- Consistency of realized products
- Less labor of non-value added tasks like testing, fixing -> versus first time quality
  - Reduction in scrap product caused by touching the product
- Adjust manufacturing process based on incoming material specs
- Reduce inventory levels -> JIT
- Safety
  - More consistent process drives less incidents/accidents
  - Less human contact -> no-touch process
  - Less production upsets
  - Less unplanned downtime
- Environmental impact/footprint
- Emissions

Barriers

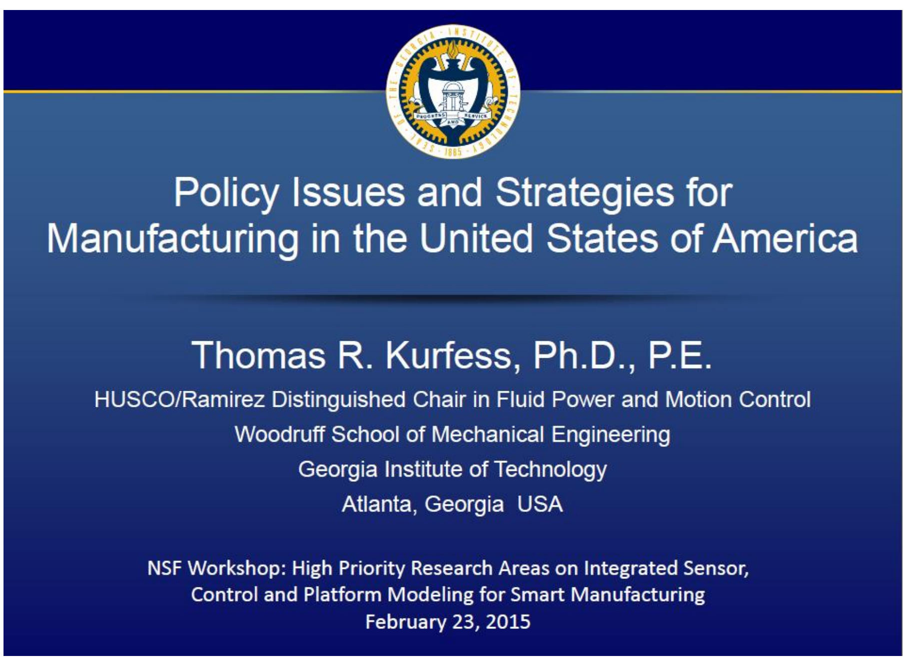
- Cost to retrofit old equipment
- Justification of projects and resources (implementation)
- Lack of measurement system to accurately measure benefits
- Lack of training resources
- Lack of capital for investment
- Need to control what you cannot measure
  - Strong business case to focus on predictive models using inferential sensors
  - Control physical properties
- Cost of sensor technology and analysis
- Lack of models that link available measurements/inputs to desired output properties
- Need to go back to first principle modeling / engineering fundamentals of process understanding
- Computational capabilities of affordable platforms

- Easy ways to calculate potential value of technology. Simple ROI calculator
- Shifts within control specs/limits of raw materials causes shifts in final product quality
    - Lack of the ability to adapt quickly to material changes
    - Accurate sampling of all incoming raw materials (trusted)

Tools:

- Roadmap for adoption of these technologies
    - Templates that are company/industry specific
- Test Beds, Tech Centers
    - Mimics/Pilot

Appendix VI: Keynote Presentations



"Our first priority is making America a magnet for new jobs and manufacturing."

- President Barack Obama
February 12, 2013

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"Now is not the time to gut these job-creating investments in science and innovation. Now is the time to reach a level of research and development not seen since the height of the Space Race."

- President Barack Obama
February 12, 2013

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Primary Recommendations from AMP SC

- 3 key areas / 16 recommendations for action
- Enabling innovation
  - improved coordination among industry, academia, and the government in R&D funding for cross-cutting technologies.
- Securing the talent pipeline
  - community college level education and enhancing advanced manufacturing university programs.
- Improving the business climate
  - tax reform, regulatory, trade, and energy policy.

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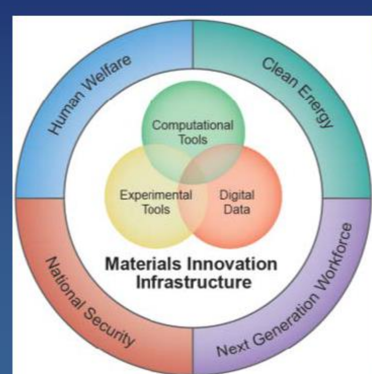
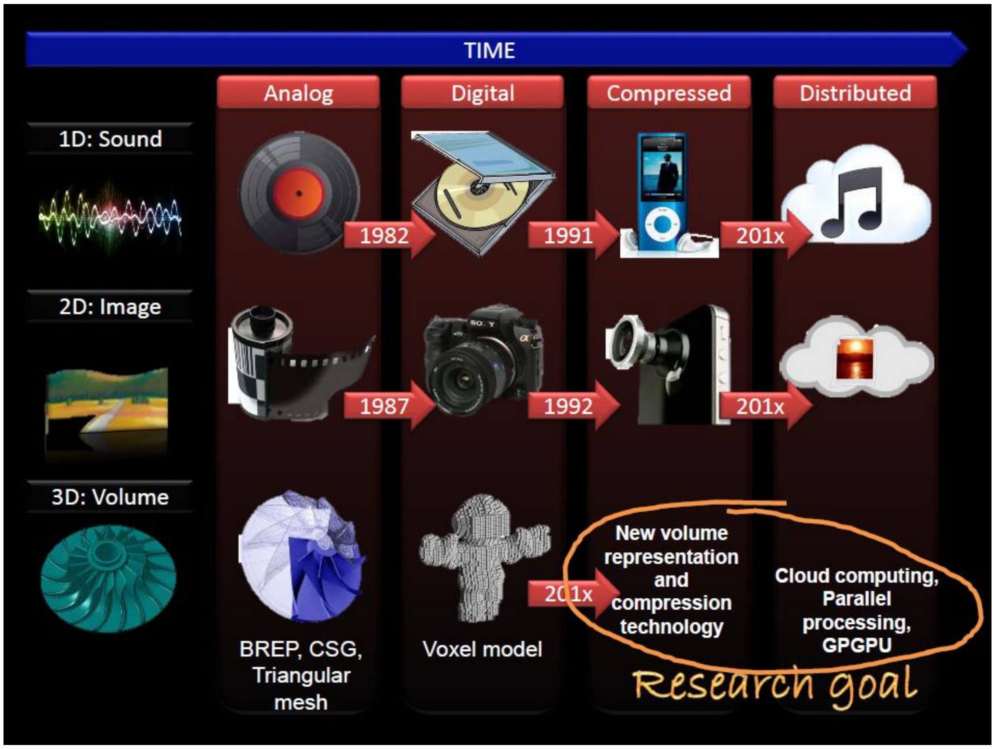
Current Institute Status (TRL 4-7)

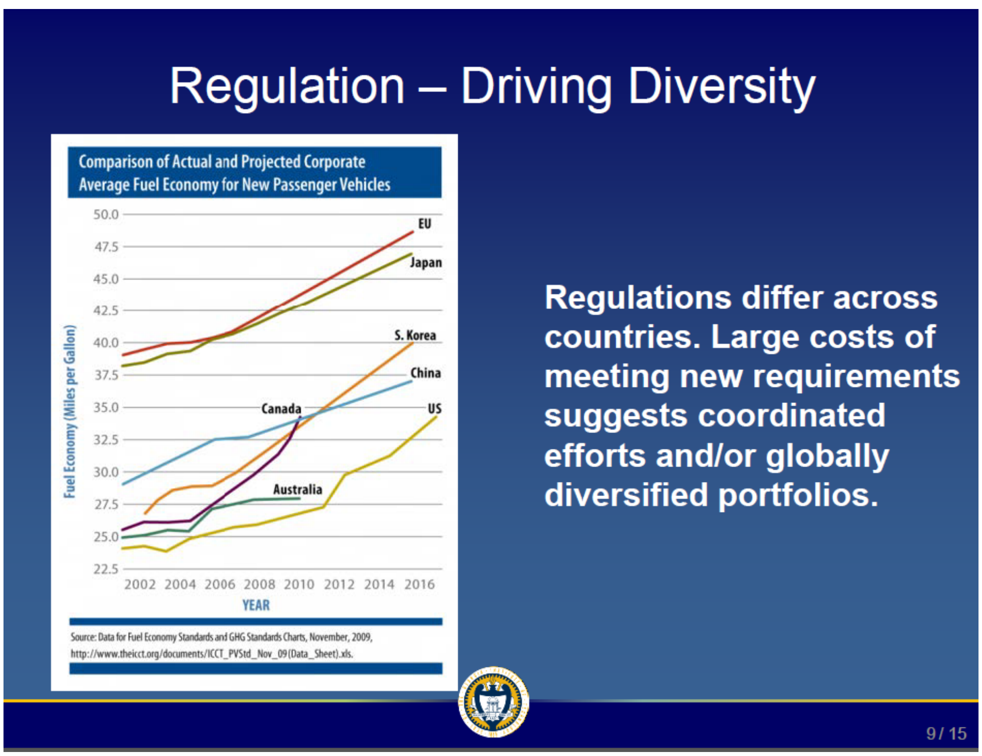
- National Network for Manufacturing Innovation (NNMI)
- Pilot – Additive Manufacturing (America Makes)
- Next – Light Weight Metals, Power Electronics, Digital Mfg., Composites, Photonics, Smart Mfg., Flex. Electronics
- Revitalize American Manufacturing Innovation (RAMI)
  - Industry Driven vs. Agency Driven

The Big Picture

- Some major initiatives
  - Robotics Initiative
  - Materials Genome Initiative
  - Big Data
- NNMI
  - Getting technology to SME's
  - New models for work force dev.
  - New models for equipment usage
  - IP issues
- MEP
- Infrastructure
- HPC
- Cloud / Connectivity
- Trillions




TIME
Analog
Digital
Compressed
Distributed
1D: Sound
1982
1991
201x
2D: Image
1987
1992
201x
3D: Volume
201x
New volume representation and compression technology
Cloud computing, Parallel processing, GPGPU
BREP, CSG, Triangular mesh
Voxel model
Research goal


Regulation – Driving Diversity
Comparison of Actual and Projected Corporate Average Fuel Economy for New Passenger Vehicles
Fuel Economy (Miles per Gallon)
50.0
47.5
45.0
42.5
40.0
37.5
35.0
32.5
30.0
27.5
25.0
22.5
2002 2004 2006 2008 2010 2012 2014 2016
YEAR
EU
Japan
S. Korea
China
Canada
US
Australia
Source: Data for Fuel Economy Standards and GHG Standards Charts, November, 2009, http://www.theicct.org/documents/ICCT_PVStd_Nov_09(Data_Sheet).xls.
Regulations differ across countries. Large costs of meeting new requirements suggests coordinated efforts and/or globally diversified portfolios.
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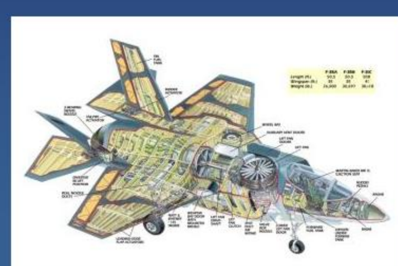
Changing Powertrain Technology

The Winds of Change in a Digital World

- Improve reputation of manufacturing
- Design and manufacturing
- Alignment of TRL 1-3 with TRL 4-9
- Sustainable ecosystem / pull vs. push
- Thinking in a completely new fashion
- A new workforce foundation



Encouraging Careers in STEM

- The President's "Educate to Innovate" initiative is leveraging private-sector partners to get students excited about STEM subjects.
  - FIRST students many more times likely to major and pursue careers in science and engineering
- "Technology shifts and increasing investments in advanced manufacturing are creating a great demand for STEM-capable students worldwide." - Paula Davis, President, Alcoa Foundation

White House, November 2009

White House Science Fair, Feb 2012

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A Few Cold Realities

- Manufacturing is high tech
- SMEs (Jobs / Economy) – Supplier vs. OEM
- Speed to market
- Standards (process vs. product)
- Productivity is up (2X every 10 years)
- Green generating green
- Transportation costs
- The days of hard transfer lines are numbered
- Open source is going to rule

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Back to the Big Picture

- Wealth creation
- Enabling SME's
- Supply chain sustainability
- A new workforce foundation
- New technical leadership for policy
- The United States of America
  - Enabling innovation
  - Ensuring the talent pipeline
- The World – Making a difference

"In times of change, learners inherit the earth; while the learned find themselves beautifully equipped to deal with a world that no longer exists." (Eric Hoffer 1902-1983)

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"Think about the America within our reach: A country that leads the world in educating its people. An America that attracts a new generation of high-tech manufacturing and high-paying jobs. A future where we're in control of our own energy, and our security and prosperity aren't so tied to unstable parts of the world. An economy built to last, where hard work pays off, and responsibility is rewarded."

- President Barack Obama
January 24, 2012

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Advanced Manufacturing Program 2.0

NSF Workshop: High Priority Research Areas on Integrated Sensor, Control and Platform Modeling for *Smart Manufacturing*

R. Shanker (Dow Chemical), K. Mikkilineni (Honeywell), and K.J. Van Vliet (MIT)

Feb 23, 2015

Washington, D.C.

AMP2.0 analyses are pre-decisional drafts.

1

Agenda

- **AMP 1.0 Background**
- **AMP2.0 Scope & Charge: Transformative Manufacturing Technologies**
- **Manufacturing Technology Area (MTA) Prioritization**
- **Recommendations for Development and Implementation**
- **Potential Applications**
- **Next Steps**

AMP2.0 analyses are pre-decisional drafts.

2

AMP 1.0 Recommendations- Enabling Innovation (2011-2012)

Table 2. Summary of Recommendations

Pillar I: Enabling Innovation	
1	*Establish a National Advanced Manufacturing Strategy* Through a systematic process to identify and prioritize cross-cutting technologies, a national advanced manufacturing strategy should be developed and maintained.
2	*Increase R&D Funding in Top Cross-Cutting Technologies* In addition to identifying a "starter list" of cross-cutting technologies that is vital to advanced manufacturing, the AMP Steering Committee has laid out a process for evaluating technologies for R&D funding.
3	*Establish a National Network of Manufacturing Innovation Institutes* Manufacturing Innovation Institutes (MIIs) should be formed as public-private partnerships to foster regional ecosystems in advanced manufacturing technologies. These MIIs are one vehicle to integrate many recommendations.
4	*Empower Enhanced Industry/University Collaboration in Advanced Manufacturing Research* The treatment of tax-free bond-funded facilities at universities should be changed in order to enable greater and stronger interactions between universities and industry.
5	*Foster a More Robust Environment for Commercialization of Advanced Manufacturing Technologies* The AMP Steering Committee recommends actions to connect manufacturers to university innovation ecosystems and create a continuum of capital access from start up to scale up.
6	*Establish a National Advanced Manufacturing Portal* A searchable database of manufacturing resources should be created to serve as a key mechanism to support access by small and medium-sized enterprises to enabling infrastructure.

AMP2.0 (2013-2014)

- Five AMP 2.0 Working Teams:
  1. **Transformative Manufacturing Technologies**
  2. Demand-Driven Workforce Education & Training
  3. National Network of Manufacturing Institutes Governance
  4. Scale-up Policy
  5. Manufacturing Image

Working Team participants include AMP *industry*, *academia*, & *labor* representatives.
Feedback on findings obtained from wider range of invited subject matter experts.

Original AMP 1.0 Technology Areas (2012)

*** NNMIs launched**

1. **Advanced sensing, measurement, and process control**
   (smart manufacturing or advanced automation)
2. **Advanced material design and synthesis**
   (including nano-materials, meta-materials, metals, coatings, ceramics)
3. **Information technologies, including visualization and digital manufacturing***
4. **Sustainable manufacturing**
5. **Nano-manufacturing (includes micro feature manufacturing)**
6. **Flexible electronics**
7. **Bio-manufacturing and bioinformatics, including proteomics and genomics**
8. **Additive manufacturing***
9. **Advanced manufacturing equipment (including testing)**
10. **Industrial robotics**
11. **Advanced forming (near-net-shape manufacturing) and joining/bonding technologies**

5

AMP2.0 Manufacturing Technology Area (MTA) Prioritization

2012: AMP 1.0 PCAST report included 11 MTAs

Nov 2013: AMP 2.0 prioritized analysis of 4 MTAs, based on poll of industry and academia on **four** criteria:

- ***i. Industry and/or market pull***
- ***ii. Cross-cutting impact on sectors***
- ***iii. US security or competitiveness implications***
- ***iv. Leveraging US strengths***

Jan 2014: AMP 2.0 completed framework documents outlining top three MTAs;.

Three MTAs were prioritized by AMP 2.0 for study and action in 2014:

1. **Advanced Materials Design, Synthesis, & Processing**
2. **Advanced Sensing, Measurement, & Process Control**
3. **Visualization, Informatics, & Digital Manufacturing**

AMP2.0 analyses are pre-decisional drafts.

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AMP2.0 Prioritized MTAs Target Different 'Scales'

1. Visualization, Informatics, & Digital Manufacturing

- **End-to-end** supply chain and enterprise level digital technologies for manufacturing
- Addresses product **life cycle**

2. Advanced Sensing, Control & Platforms for Manufacturing

- Advanced technology implementation at the '**shop floor**'
- Enterprise level integration key to **decision making**

3. Advanced Materials Manufacturing

- Addresses **materials** related challenges

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MTA 2. Advanced Sensing, Control and Platforms for Manufacturing (ASCPM)

Enables a holistic treatment of data, information and models in manufacturing, and enables decision making and interoperation of cyber and physical assets

DRIVERS

- $60 B legacy automation footprint in US across sectors, but adoption in SMEs lags
- Direct impact on resource utilization and competitiveness, especially for SMEs
- The last and most vital link to translating of Advanced/Digital Manufacturing to actual production
- Opportunity to demonstrate initial value within 2-3 years, with sustained impact

CHALLENGES & GAPS

- Risk and complexity of implementation, workforce availability for implementation, especially for SMEs
- Open standards and interoperability for manufacturing devices, systems, and services
- Platform infrastructure for orchestration of public and private data and software across heterogeneous systems
- Software-service oriented platforms for manufacturing automation
- Noninvasive, real-time measurement solutions for factory environments
- Health management for manufacturing equipment and systems
- Theory and algorithms for model-based control and optimization in the manufacturing domain
- Modeling and simulation at temporal and spatial scales relevant across manufacturing

AMP2.0 analyses are pre-decisional drafts.

8

Key Observations

- **A national, strategic view of Adv. Mfg. Tech. investments is needed to sustain public/private collaboration**
  - Primary AMP 1.0 recommendation on 'Enabling Innovation'
  - Ensures Private-Public coordination and leveraging common capabilities
  - Enables 'portfolio management' of manufacturing technology investments
  - Drives sustainable models of collaboration across the TRL/MRL spectrum
  - Enables a framework for pipeline investments in R&D (TRL 1-4)
- **Enhance access and reduce risk to drive adoption of late stage technologies**
  - Consistency of policies and incentives for adoption of adv. mfg. tech.
  - Deployment of existing infrastructure and capabilities to help manufacturing
- **Common accelerators for technology adoption**
  - Standards and Interoperability of mfg. hardware and software
  - Security, data privacy and trust across the supply-chain
  - Workforce skills at all levels, including advanced degree (MS and PhD) levels
  - Precompetitive public-private partnership R&D at low TRL/MRL levels

Pillar I: Enabling Innovation

Recommendation #1	***Establish a national strategy for securing U.S. advantage in emerging manufacturing technologies*** with a specific national vision and set of coordinated initiatives across the public and private sectors and all stages of technology development. This should include prioritized manufacturing technology areas of national interest, leveraging the technology prioritization and analysis process developed by the Advanced Manufacturing Partnership, and should facilitate management of the portfolio of advanced manufacturing technology investments.
Recommendation #2	***Create an Advanced Manufacturing Advisory Consortium*** to provide coordinated private-sector input on national advanced manufacturing technology research and development priorities
Recommendation #3	***Establish a new public-private manufacturing research and development infrastructure to support the innovation pipeline,*** which complements Manufacturing Innovation Institutes at earlier and later technology maturation stages, through the creation of manufacturing centers of excellence (MCEs) and manufacturing technology testbeds (MTTs) to provide a framework that supports manufacturing innovation at different stages of maturity and allows small and medium-sized enterprises to benefit from these investments.
Recommendation #4	***Develop processes and standards*** enabling interoperability of manufacturing technologies; exchange of materials and manufacturing process information; and certification of cybersecurity processes for developers of systems.
Recommendation #5	***Create*** – through the National Economic Council, the Office of Science and Technology Policy, and the implementing agencies and departments – ***a shared National Network for Manufacturing Innovation (NNMI) governance structure*** that can ensure a return on investment for the NNMI's many stakeholders by including input from various agencies as well as private sector experts, organized labor and academia.

Pillar II: Securing the Talent Pipeline

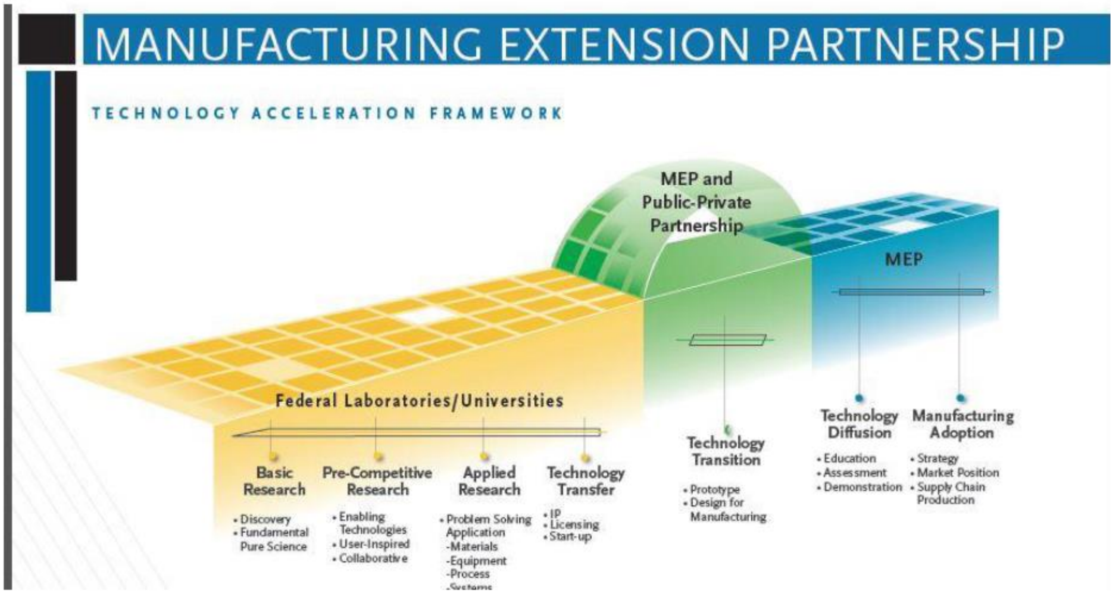
Recommendation #6	***Launch a national campaign*** to change the image of manufacturing and support National Manufacturing Day's efforts to showcase real careers in today's manufacturing sector
Recommendation #7	***Incent private investment in the implementation of a system of nationally recognized, portable, and stackable skill certifications that employers utilize in hiring and promotion,*** by providing additional funds that build on investments being made through the Department of Labor and Department of Education Trade Adjustment Assistance Community College and Career Training (TAACCCT).
Recommendation #8	***Make the development of online training and accreditation programs eligible to receive federal support*** through federal jobs training programs
Recommendation #9	***Curate*** the documents, toolkits and playbooks that have been created by AMP2.0 to further scale and replicate these important talent development opportunities, via the Manufacturing Institute.

Pillar III: Improving the Business Climate

Recommendation #10	***Leverage and coordinate existing federal, state, industry group and private intermediary organizations*** to improve information flow about technologies, markets and supply chains to small and medium-sized manufacturers.
Recommendation #11	***Reduce the risk associated with scale-up of advanced manufacturing*** by improving access to capital through the creation of a public-private scale-up investment fund; the improvement in information flow between strategic partners, government and manufacturers; and the use of tax incentives to foster manufacturing investments.

	Implementation
Recommendation #12	***The National Economic Council (NEC) and the Office of the Science and Technology Policy (OSTP), within 60 days, should submit to the President a set of recommendations*** that specify: (1) the ongoing EOP role in coordinating the federal government's advanced manufacturing activities; and (2) clear roles and responsibilities for federal agencies and other federal bodies in implementing the above recommendations.

Investments (public/private) across the development pipeline



AMP2.0 analyses are pre-decisional drafts. 13

Trends in use of Technologies

- Drive for improved returns
  - On assets
  - On Cash
- Dynamic, 'demand-driven' supply chain optimization
- Definition of 'core competencies' expands but pressure on investments continue

AMP2.0 analyses are pre-decisional drafts. 14

Applications for ASCPM

- Classical continuous and discrete process control
  - Many examples in industry
- Development of many new markets
  - Ag, Pharma, Energy Efficiency, Chemicals, Materials and Consumer Durables

Approaches to develop ASCPM capabilities

- Development of a clear roadmap
- Integration of H/W, S/W and IT into Solution Ware
- Focus on interoperability and easy deployment
- De-risk implementation through partnerships such as NMMIs and MEPs