Advanced Manufacturing Enterprise

Strategic Baseline

15 July 2011

Cleared for public release 27 Sep 11
Case Number: 88ABW-2011-5178

Prepared for:

John D. Russell, D.Sc.
Program Manager, Defense-Wide Manufacturing Science and Technology Program

Brench L. Boden
Chair, JDMTP Advanced Manufacturing Enterprise Subpanel

Prepared by:

Scott Leonard and Mel Hafer
Northrop Grumman Technical Services, Inc.
Acknowledgments

The study team would like to acknowledge the contributions of the following individuals and organizations.

The Advisory Panel included:

- William Kessler, Tennenbaum Institute, Georgia Tech
- Michael McGrath, Analytic Services Inc.
- Rusty Patterson, National Council for Advanced Manufacturing (NACFAM)

Others who were interviewed or provided their written inputs include the following.

- Brench Boden, Air Force Research Laboratory
- Kevin Carpentier, CNST/ATI
- John Christensen, OSD ManTech Office (Contractor)
- Rebecca Clayton, Office of Naval Research
- Scott Frost, Analytic Services Inc.
- Paul Huang, U.S. Army Research Laboratory
- Steve Luckowski, U.S. Army ARDEC
- Al Sanders, NDIA JCSEM M&S Sub-Committee Chair, and Honeywell Aerospace
- David Stieren, NIST Manufacturing Extension Partnership Program
- Mark Traband, Penn State University
- Steve Turek, Air Force Research Laboratory
- Paul Villanova, U.S. Army ARDEC
- Roy Whittenburg, U.S. Army ARDEC (Contractor)

Their keen interest in the issues and their willingness to share their time, writings, and thoughts are greatly appreciated.
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Executive Summary

The purpose of this Advanced Manufacturing Enterprise (AME) Strategic Baseline report is to analyze current thinking in the AME field and use that information to produce a set of recommended near-term technology investment areas and leadership action items. A time horizon for these investments and actions was set at “less than five years” in order to bound the report’s analysis. Given this limited time horizon, the report is not intended to explore a long-term AME vision, future state, or implementation strategy; that task remains in front of the AME subpanel and the AME community of OEMs, suppliers, universities, and other Government offices.

There are several modern manufacturing challenges that are common to many defense manufacturers, no matter what types of systems, components, or materials they make. Among these challenges are highly distributed manufacturing, product development costs, smaller lot sizes, and frequently changing requirements. AME is an umbrella term used by the Department of Defense’s Joint Defense Manufacturing Technology Panel (JDMTP) AME Subpanel to describe the many approaches being taken by government, industry, and academia to address these manufacturing challenges. AME is defined as the following:

The Advanced Manufacturing Enterprise (AME) is a set of robust manufacturing strategies & integrated capabilities that dramatically reduce the cost and time of producing complex systems in today’s global manufacturing enterprises. These strategies include:

- an industrial information infrastructure that can pass all relevant data between design, fabrication, test, and sustainment operations quickly and without distortion, error, or omission;
- advanced engineering tools and practices that eliminate multiple design, prototype, and test iterations required for product or process qualification; and,
- supply network integration technologies and management practices that provide connectivity and enhance collaboration among disparate and geographically distant organizations in the supply network, and relentlessly shorten lead times.

The potential benefits of implementing AME practices are greatly reduced production times and billions of dollars in avoided costs. The Department of Defense, and more specifically, the DASD (Manufacturing and Industrial Base Policy (MIBP)), should both lead the AME movement and manage a portfolio of AME technology development/demonstration investments. There are many barriers to implementing AME practices, and industry will not overcome those barriers in a timely way without DoD leadership and investment.

To study current thinking in the AME field, the study team gathered hundreds of published briefings, papers, and articles from government, industry, and academia. These documents described several communities of interest that relate highly to AME practices, and asserted many relevant targeted problems, solution strategies, expected benefits, and barriers to implementation.
Strategies

The 100-plus solution strategies were grouped into seven “consolidated solution strategies,” shown in the following list. The supporting details for each strategy are shown in Chapter 4.

Strategy 1: Develop tools to enable better designs.

These tools include those that would increase design automation, improve model-based system verification, utilize platform based engineering, and facilitate producibility analysis, and other capabilities.

Strategy 2: Enhance interoperability.

Enhance interoperability through technology development & implementation initiatives such as: establishing interface protocols and standard formats. In addition, move forward with leadership and policy initiatives such as providing a forum for driving all electronic enterprise standards and organizing an information backbone of relevant standards. Promote standards, but not mandated common tools.

Strategy 3: Develop and implement improved 3D Technical Data Packages.

Invest in technology development and implementation initiatives, such as: methods for improved data validation, pilot demonstrations, and building the business case for implementing 3D TDPs. Promote leadership and policy initiatives such as updates to MIL-STD 31000, revising existing standards, and supporting use of 3D TDPs in defense procurement contracts.


Develop tools and methods such as: metrology tools for real-time handling of manufacturing information, sensor networks for data capture and machine-to-machine communication, and manufacturing equipment that is self-aware (via sensors) so it can recognize its condition and report it to interoperating devices.

Strategy 5: Develop tools and methods to improve supply network integration and management.

Develop tools and methods such as: networked sensors throughout the enterprise for enhanced communication, planning and control; robust engineering change management tools that communicate changes immediately throughout the supply chain; sourcing tools that streamline the sourcing process; supplier risk assessment tools; streamlined processes for managing and protecting intellectual property.
Strategy 6: Develop methods for manufacturing that are more adaptable to changing product requirements.

Develop manufacturing methods that apply the adaptation strategies of semiconductor foundries; allow rapid setup and processing; facilitate low-volume production runs with the same economies as high-volume runs.

Strategy 7: Develop tools to enhance trusted systems (components that are neither counterfeit nor tampered with) and cyber security.

Implement multi-level security in collaboration tools and other open interfaces; adopt design methods and tools for system assurance that detect malice; isolate suspect components to make them not part of the enduring core; and use of trustworthiness assessment tools.

Recommendations

In addition, this report offers the following six recommendations for MIBP and the AME Subpanel.

Recommendation 1: Invest DoD funds to accelerate implementation of AME practices within the defense industrial base.

Chapters 1 and 2 of this report make the case that DoD should invest funds in developing and implementing AME technologies. Doing so will accelerate the implementation of AME practices and bring tremendous reductions in cost and lead time while improving U.S. manufacturing competitiveness. The specific investment areas are described in Chapter 4.

Recommendation 2: Engage with the most appropriate communities of interest and provide leadership that coordinates their efforts to the benefit of all.

The DoD already has the appropriate organizations in place to lead: the recently established Manufacturing and Industrial Base Policy (MIBP) office and the Joint Defense Manufacturing Technology Panel’s AME Subpanel. Relationships with relevant industry organizations such as NACFAM, NDIA, and AIA are well established. In conjunction with other government and industry stakeholders, an AME executive-level steering committee should be formed, and AME practitioner meetings and conferences should be convened. Together, these organizations should take the lead in advocating policies and standards to support AME implementation.

Recommendation 3: Apply the lessons of the Quality Movement to implementing AME, and Consult Experts for Guidance on Enterprise-Level Change Management.

Everything the prior generation learned from the Quality Movement about implementing change should be applied to the AME movement. In the 1990’s, there were plenty of case studies describing failed attempts to implement quality initiatives. In general, these were not failures of quality tools, but rather, failures to properly manage change. Properly applying the Quality
Movement’s lessons of industry transformation (particularly with regard to executive leadership and culture change) to AME implementation will help overcome this hurdle. In addition, experts on how enterprise-level change can be successfully managed should be consulted in order to define more specific strategies for transforming the current defense industry into an advanced manufacturing enterprise.

**Recommendation 4: Engage the support of executive-level champions for AME implementation within DoD and industry.**

For AME implementation to be well underway within 10 years, high-level executives within DoD and industry must become AME champions now. To achieve their buy-in and support, the AME Subpanel and MIBP should work towards very effectively articulating the compelling reasons for implementing AME. Effectively making the case will require describing AME with return-on-investment data (in terms of time and money saved) and without jargon.

**Recommendation 5: Learn in-depth from case studies such as the Boeing 787 and Lockheed Martin F-35 implementations of AME practices.**

Both the Boeing 787 and Lockheed Martin F-35 programs applied AME practices to a significant degree in order to manage their global supply networks. Both programs are now suffering from high-profile delivery delays and cost overruns, which makes it likely their cases will be raised for consideration whenever a large future investment in AME is discussed. There is an opportunity to learn from these cases: what went right, and what should be done differently next time? The lessons should be learned and documented for defense manufacturing industry decision makers. Advocates need to be able to tell the story that AME practices were not the problem, they were just not yet mature enough to be the 100% solution. With sponsorship, AME will mature and address the problems that really did create cost overruns and delays.

**Recommendation 6: Develop a dashboard of metrics for AME implementation.**

Although one of the key goals of implementing AME practices is to reduce costs, metrics in addition to cost should be developed. Experience with the Quality Movement showed that it was challenging to measure cost savings due to quality initiatives. Other metrics should be used to show that AME implementation efforts are making progress.
Chapter 1. Addressing Defense Manufacturing Challenges

1.1 Purpose of this Strategic Baseline Report

Advanced Manufacturing Enterprise (AME) has emerged as a descriptor of the public and private sector pursuit of robust manufacturing strategies and integrated capabilities that reduce cost and time of producing complex systems in today’s global manufacturing enterprises. The OSD ManTech office is a major sponsor of R&D investments addressing enterprise-level technical needs, and in 2010 the Joint Defense Manufacturing Technology Panel (JDMTP) reestablished the AME Subpanel. The charter of the AME Subpanel includes leading the establishment of the appropriate JDMTP investment strategy for AME.

This report was commissioned to serve a specific and immediate need for the AME Subpanel, other AME sponsors and the community. The AME Subpanel requires time to develop and articulate a priority set of investment requirements in this complex area; hence, an acute need exists for a “running start” whose point of departure is the baseline of ongoing activities in candidate AME investment areas. This report was developed with the precise intent of analyzing current thinking in the AME space to produce such an initial set of recommendations that are grounded in current understanding and knowledge.

An artificial time horizon of “less than five” years was established at the outset to focus the NGTS analysis. The focus on current thinking, literature, and presentations limits the scope of the baseline to those items already identified and leaves the definition of the “full scope of needed investments for AME” for the future. The AME Subpanel and this report’s authors understand that these limitations restrict the range of capabilities considered, and that more work is needed to set the priorities necessary to realize the full potential of AME outcomes.

However, given the urgency of the need – and the capacious nature of the topic area – this report succinctly satisfies the JDMTP and AME Subpanel need for that running start with the realization that additional insights will come in the future. The AME subpanel members bring varied experience and understanding of service-specific technical needs to the planning process; this report provides a framework and strategic baseline to enhance the group’s capacity for recommending high priority investments for the next few years.
1.2 Defining the Advanced Manufacturing Enterprise

AME is defined as the following:

The Advanced Manufacturing Enterprise (AME) is a set of robust manufacturing strategies & integrated capabilities that dramatically reduce the cost and time of producing complex systems in today’s global manufacturing enterprises. These strategies include:

- an industrial information infrastructure that can pass all relevant data between design, fabrication, test, and sustainment operations quickly and without distortion, error, or omission;
- advanced engineering tools and practices that eliminate multiple design, prototype, and test iterations required for product or process qualification; and,
- supply network integration technologies and management practices that provide connectivity and enhance collaboration among disparate and geographically distant organizations in the supply network, and relentlessly shorten lead times.

One of the challenges of defining “Advanced Manufacturing Enterprise” is separating what is under the umbrella of AME from what is not. Many papers and organizations use the words “advanced manufacturing” to describe the latest improvements in shop floor technologies. They use the words “advanced manufacturing” to describe new technologies for forming, cutting, or joining materials. These shop floor technologies are generally outside the scope of AME. On the other hand, technologies that enhance communication and control over processes that form, cut, or join materials are most likely within the scope of AME.

The Science and Technology Policy Institute compiled many definitions of “Advanced Manufacturing,” noting that most of the surveyed sources agreed that an appropriate definition should be dynamic. Because the manufacturing improvement frontiers are constantly changing, the methods of “advanced manufacturing” are always changing too. Perhaps the definition most useful to this discussion of AME is quoted from a 2002 paper published by the National Defense University, which defines advanced manufacturing as “the insertion of new technology, improved processes, and management methods to improve the manufacturing of products.” This definition applies whether one is discussing manufacturing developments of 1910, 2010, or beyond.

Because AME manufacturing improvements are more about design practices, communication and control than about physical transformation of materials, they can be applied by many manufacturers, no matter what types of systems, products, components, or materials they make. In 1810, AME might have referred to the concept of making products with interchangeable parts. In 1910, AME might have referred to Henry Ford’s assembly line production technology. In

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1 There are many verbs in addition to “form, cut, and join” that could be used here. Consider “grow, grind, drill, polish, heat, cool, mold, press, assemble” and others.
1990, AME might have referred to the tools of the quality movement. In 2011, AME generally refers to technologies and processes that enhance:

- Communication and collaboration between people, organizations, software, and machines that:
  - are highly distributed and distant (around the world) from each other, and
  - perform very different functions (design, fabricate, test, or transport).
- Design and testing of products and processes through use of digital modeling & simulation, rather than through prototyping and physical testing.

These improvements make a complex, highly distributed manufacturing enterprise more effective, efficient, manageable, and responsive.

- Communication and collaboration improvements help to tighten the links between customer requirements and product performance, and reduce delays and rework. They also increase the level of control that decision-makers have over their supply network.
- Modeling & simulation improvements enable better product and process designs while reducing the cost and time required for physical prototyping and testing.

Put another way:

Advanced Manufacturing Enterprise (AME) is composed of one or more highest-level initiatives, each of which applies multiple processes and technologies to dramatically improve the cost, speed, and quality of manufacturing across many industrial and geographic boundaries. The initiatives have life cycles; as older initiatives achieve widespread adoption and eventual obsolescence, new initiatives emerge. In 2011, two highly prominent initiatives are the following.

1) Digital Communication and Interoperability – Development and implementation of tools and processes for improved digital communication and interoperability between all design, manufacturing, testing and sustainment activities in the manufacturing enterprise, with the purpose of dramatically reducing waste caused by sub-optimal communication and interoperability.
2) Modeling and Simulation – The application of ever-increasing computing power to model more things more effectively, to reduce the cost of design iterations, prototyping, and testing.

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4 The “Quality Movement” refers to the many quality improvement methods that were popular in the 1990s such as Total Quality Management, ISO-9000, Lean Manufacturing, Six Sigma, Theory of Constraints, Just in Time, and Re-Engineering.
1.3 The Scope of AME

The scope of the AME needs to address the *entire* enterprise – relationships between the organizations (public and private) in the enterprise, value stream integration of functions within each organization in the enterprise, integration of activities within functions, individual skills/behaviors, and the relationships between all of the above. The means for achieving the outcomes of AME involve strategies, technologies, and skills/behaviors. Finally, moving from today’s strategies and capabilities to an AME future state requires the sponsors and community to address the challenges of communication among the public-private participants as well as an aligned strategy for transformation or change.

1.4 AME From the ManTech Executive-Level Perspective

There are several modern manufacturing challenges that are common to many defense manufacturers, no matter what types of systems, components, or materials they make. Among these challenges are the following.⁵

- **Highly Distributed Manufacturing.** The enterprise for design and manufacture of defense products is increasingly distributed. Original Equipment Manufacturers focus on systems integration, leaving most fabrication and assembly to a highly distributed network of smaller manufacturers. Global partnerships have benefits, but create new problems. There are serious technical and organizational barriers to fully effective collaboration.

- **Product Development Costs.** Product development takes too long and costs too much. Systems engineering tools have not kept up with increasing system complexity. Engineering change costs are high. Warfighters cannot wait a decade or more for products needed to address today’s fight. Design and production information is created and lost repeatedly over a system’s life cycle.

- **Smaller Lot Sizes and Frequently Changing Requirements.** Modern manufacturers struggle to rapidly and efficiently produce smaller lot sizes or respond to changing requirements. There is a need to manufacture efficiently even in low volumes, and to increase flexibility. Ways must be found to rapidly qualify and insert new technology.

The Advanced Manufacturing Enterprise (AME) is an umbrella term used by the Department of Defense’s Joint Defense Manufacturing Technology Panel (JDMTP) to describe the many approaches being taken by government, industry, and academia to address these manufacturing challenges. It also represents a new, fourth programmatic “bin” in the JDMTP’s taxonomy of technical investment areas, the other three encompassing (1) electronics, (2) composites, and (3) metals processing and fabrication technologies. This AME Strategic Baseline examines the many approaches, identifies their common themes, and recommends actions that the JDMTP’s AME Subpanel and OSD Office of Manufacturing and Industrial Base Policy (MIBP) can take to accelerate the implementation of AME solutions within the defense industry.

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To address many of today’s defense manufacturing challenges, the Department of Defense’s Joint Defense Manufacturing Technology Panel (JDMTP) established the Advanced Manufacturing Enterprise (AME) Subpanel. The AME Subpanel defines its scope as encompassing “the technologies, processes, and practices that foster rapid, superior execution of manufacturing enterprises across the life cycle of manufactured products and systems.” AME investments address above-the-shop-floor technologies and intelligent business practices enabling new ways of doing business across an increasingly complex and networked manufacturing landscape. AME visualizes a highly connected and collaborative manufacturing environment among the multiple players in system development, production, and sustainment. The AME Subpanel identifies the following four investment focus areas:

- **Model Based Enterprise or “Building the Digital Thread”** – Drive a continuous flow of integrated design, analysis and manufacturing information throughout the product/system life cycle through:
  - Advanced modeling and simulation
  - Design optimization tools
  - Virtual prototyping
  - Data standards efforts

- **Manufacturing Networks or “Connecting the Enterprise”** – Enable seamless interoperability of data and processes across organizational boundaries through:
  - Advanced supply chain management practices
  - Enterprise integration technologies
  - Tools to enable seamless collaboration

- **Intelligent Manufacturing Planning and Execution** – Create agile and adaptive manufacturing capabilities that integrate factory floor resources to rapidly deliver advanced systems to the warfighter through:
  - Factory integration for autonomous operations
  - Advanced production planning and scheduling

- **Industrial Base Infrastructure and Readiness** – Actively support initiatives and policies to ensure manufacturing infrastructure health and U.S. global manufacturing superiority through:
  - Manufacturing readiness Body of Knowledge development
  - Active collaboration to enable effective implementation and sustainment of manufacturing technologies.

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The DoD Manufacturing Technology Strategic Plan has as Thrust 2 of its four strategic thrusts, “Active support for a highly connected and collaborative Defense Manufacturing Enterprise.” The AME Subpanel is most directly concerned with Thrust 2, and it “enables a strong organizational focus on Strategic Plan Thrusts 2, 3, & 4, improving program “balance” across all four thrusts.” A diagram of the strategic thrusts is in Figure 1.

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8 “The Advanced Manufacturing Enterprise – DMC 2010”, Brench Boden, 29 November 2010 briefing at DMC.
The Air Force Manufacturing Technology Program Vision\(^9\) lists four strategic thrusts, and two of them tie directly to AME. Although these thrusts are in an Air Force plan, the ideas apply equally well to all of defense manufacturing.

The first strategic thrust that relates to AME is “A Cradle-to-Cradle Digital Thread:”

\begin{quote}
A core element of the future industrial base is the concept of a digital thread, defined as technologies that enable all participants and contributors to the weapon system, at any point of the life-cycle, to access the same computer-based technical description of the product. This technical description refers pertinent product and process data, such as design concept, 3-D geometry, material specifications, manufacturing tool paths, simulation performance, engineering analysis, logistics activities, or reliability estimates. Cradle-to-cradle refers to a design and development philosophy that considers the entire product life cycle value stream, including the potential reusability of each material and component and the impact on the environment. Thus, the core goal of this thrust is the ever-present access to a single, digital representation of a system design throughout all potential uses and re-uses of the material.
\end{quote}

The agile industrial base of tomorrow will be fueled by information. The digital definition of the product and all knowledge created during the design, fabrication, assembly, test, operation, maintenance, and disposal must become a single “thread” connecting all of these lifecycle stages and the disparate entities that execute during those stages. Constant access to a single, digital definition that can be used in various levels of modeling and simulation will drive huge decreases in cost and time and allow better optimization of highly complex tradeoffs. The integrity of data supporting sustainment, modification, and reuse will have huge payoffs through the lifecycle.

Essential attributes to be pursued include a commitment to capturing, organizing, and storing relevant data (e.g., product lifecycle management), physics based models for manufacturing technologies developed and demonstrated for all life cycle aspects of performance and material reuse, and the capability for distributed, multipurpose collaboration. Required tools must be developed for capture of utilization data, including as-designed, as-built materials, and service/operational environment history traced to the component level. These models and information can be closely linked to improved analysis of alternatives prior to Milestone A and are essential for long-term sustainment objectives such as health monitoring and condition-based maintenance.

The second strategic thrust that relates to AME is “A Responsive, Integrated Supply Base:”

\begin{quote}
The vision of an agile manufacturing base embraces the notion that the product realization enterprise can be assembled relatively quickly, possibly across sectors and international boundaries. The defense industrial base consists of a very few prime contractors whose role has become focused on formation of partnerships and systems integration, while the great many second and third-tier suppliers, all of which require the ability to operate collaboratively, handle more and more detailed design and component/subsystem
\end{quote}

manufacturing. The Air Force as a customer requires a new toolset featuring the capabilities for analyzing, indentifying, and managing risks and critical issues in tomorrow’s responsive, integrated industrial base.

Delivering rapid response requires that the Air Force have manageable access to and management of the future industrial base, with capability to identify and form agreements quickly with suppliers whose capabilities and availability are known. Underpinning this agility will be tools and resources for better insight into suppliers’ self-declared process capabilities, certification of those capabilities, cost models, and quality data. A new set of supply chain management principles will lend structure and accountability to relationships from the warfighter to the smallest supplier, and furnish predictive models for the life cycle. Supply chains for new product development can be evaluated and designed as part of the product to avoid unforeseen capability issues or material shortages. Risk analysis through the supply chain will be a regular and valued exercise shared by prime contractors, acquiring offices, and the sustainment community.

The Air Force Manufacturing Technology Division hosted a workshop in March 2009, including 120 invited participants from government, industry, and academia. Post-workshop analysis of the data collected identified fifteen prioritized high-level trends for defense manufacturing. Four of the seven highest-prioritized trends related directly to AME, and are shown in Figure 2.

<table>
<thead>
<tr>
<th>Rank Order</th>
<th>High-Level Trend</th>
<th>Trend No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Increased leveraging of product and process modeling &amp; simulation methodologies</td>
<td>T10</td>
</tr>
<tr>
<td></td>
<td>• Growing need to address tech / process data standardization, transfer, and archiving</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Availability of increasingly elaborate virtual modeling &amp; simulation methods to address both component / product and system / enterprise manufacturing issues</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Growing interest in value of industrial base war gaming and exercises to yield insight and innovation</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Demand for rapid and agile acquisition capabilities to match reduced technology refresh cycles</td>
<td>T8</td>
</tr>
<tr>
<td></td>
<td>• Shorter technology life cycles, higher technology refresh rates, driving shorter upgrade cycles and need for more agile acquisition capabilities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Faster paced technology deployment by adversaries putting higher value on rapid acquisition response</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Increasing frequency of disruptive technology events requiring more agile acquisition processes to exploit opportunities</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Supply chains increasingly dynamic, global, evolving</td>
<td>T1</td>
</tr>
<tr>
<td></td>
<td>• Increasing rates of change, sector clock speeds</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Much greater global connectivity, interactivity, dispersion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Global sourcing and COTS use continuing to expand</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Increased need for small lot size, more agile, and more affordable defense manufacturing methods / processes</td>
<td>T13</td>
</tr>
<tr>
<td></td>
<td>• Pervasive focus on affordable tools, tooling, and tool-less manufacturing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Increased use of Direct Digital Manufacturing methods and capabilities</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: High Level Trends Relating to AME

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1.5 AME Top-Level Perspectives Outside of ManTech

A review of the literature suggests that 99% of the people who are writing about AME-related topics never refer to it as the “advanced manufacturing enterprise.” Instead, some authors use a broad name and then offer a list of topics that overlaps with AME’s key topics.

- The Science and Technology Policy Institute describes “Distributed, Rapidly Responsive, Complex Product Realization” by discussing automatic, flexible manufacturing technologies; online problem diagnosis and self-correcting capabilities at the enterprise level; real-time tracking of manufacturing flows across the enterprise; single-unit manufacturing and rapid reconfiguration; machining processes that are measured and controlled in situ and in real time; advanced modeling and simulation; mass customization; open innovation manufacturing; network centric manufacturing; and highly distributed manufacturing called “cloud producing.”

- Shen and Norrie list the following requirements for Next Generation Manufacturing Systems: enterprise integration, distributed organization, heterogeneous environments, interoperability, open and dynamic structure, cooperation, agility, scalability, fault tolerance, and integration of humans with software and hardware.

- Chituc writes about Distributed Manufacturing Systems and Manufacturing Engineering Systems, and describes the following challenges and issues: clients changing demands, high diversity of standards for e-communication, seamless interoperability in networks of enterprises, scalability, optimal decision making, self-adaptability, and self-improvement.

Other perspectives from both within and outside of the ManTech community are described in detail in Chapter 3.

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Link may be broken, but abstract at: http://www.cs.uvm.edu/~kais/Schedule/Vol-E1-E2-abstracts.shtml
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Chapter 2. Why Should DoD Lead and Invest in AME Implementation?

Why should the Department of Defense, and more specifically, OSD MIBP, lead and invest in AME development and implementation? The short answer is, “DoD should lead because it is the government’s largest customer of the manufacturing industry. DoD also will realize the benefits of dramatic cost avoidance and shorter lead times within the defense industry much sooner if it leads and invests.” A more detailed answer is in the sections that follow.

2.1 DoD Leadership is Required to Achieve AME Goals

The Office of Manufacturing and Industrial Base Policy (MIBP) is in a strong position to provide orchestrating leadership across DoD and industry in the development and implementation of AME practices. As its name indicates, MIBP owns the two most relevant areas: manufacturing and industrial policy. MIBP should take responsibility for leading the AME movement. MIBP also oversees the Joint Defense Manufacturing Technology Panel’s (JDMTP) AME Subpanel, which should execute MIBP’s strategy and manage the AME portfolio of project investments. MIBP has established relationships with relevant industry organizations such as NACFAM, NDIA, and AIA. In conjunction with other DoD organizations, other government agencies, and industry stakeholders, MIBP should establish an AME executive-level steering committee. MIBP should also convene practitioner meetings and industry conferences.

This leadership is often necessary because the defense industry is not sufficiently structured or incentivized to adopt AME practices on its own. Even if leading system integrators such as Lockheed Martin and Boeing try to bring AME practices to their supply networks, the changes will be impeded by these barriers and others:

- Cost savings from AME practices come out of industry’s revenue and profitability (lower cost = smaller contract = lower revenue = lower profits)
- The CAD/CAM and machine software vendors who are in an ideal position to improve interoperability will resist because AME steers them to put their competitive advantages at risk
- The nature of the competition in defense manufacturing is inadequate to drive AME adoption by itself
- There is a substantial up-front investment required, often beyond the justifiable business case of any one company or even an organized consortium of companies.
- Cultural resistance to change will slow progress.

The National Science and Technology Council’s Interagency Working Group (IWG) on Manufacturing R&D observed this key barrier: the development of the new technologies needed to implement AME often will not bring returns to the individual private sector organizations that devote resources to the development efforts. The IWG asserts that because it is so difficult to profit from developing the technologies, the Federal government must assist in their
development in order for the technologies to be developed and widely adopted, and to create the savings industry-wide.  

Because of these barriers, AME practices will not significantly penetrate the defense industrial base unless DoD both leads change (through policy, requirements, and coordination) and shares the cost of change (through investment in technology development and implementation).

The AME movement in 2011 is very similar to the quality movement (Lean, Six Sigma, ISO 9000) of 1993. The compelling case for reducing costs and improving a firm’s competitive position was not sufficient to inspire the necessary change. Most suppliers (defense and commercial) resisted adopting quality movement practices until their customers forced them to change or perish. The defense industry resisted quality movement practices until the DoD showed leadership and funded quality improvement initiatives. The resistance was rational at the surface level; cost savings to the government implies revenue reductions to industry.

**DoD must lead and invest if AME is to be substantially implemented by the defense industrial base within a decade. The challenges are too large to defer to industry alone, and the cost savings are too great to delay for another generation.** While several communities of interest (described in detail in Chapter 3) are developing AME technologies and processes, they lack both coordination and funding. This report’s review of the communities of interest reveals many commonalities among the communities’ activities and interests. However, the fact that a community is publishing papers and presenting at conferences to deliver the message of needed change does not mean the community has the top-level buy-in or the funding needed to develop the tools and implement the changes without government help. Indeed, several papers call for public-private partnerships to move towards the stated goals. In addition, because these programs are being planned and executed independently, there can be missed opportunities to benefit from each others’ efforts.

### 2.2 What Costs Could AME Practices Avoid?

How much money does industry spend because it lacks adequate digital interoperability and supply network integration? Several studies have been done to quantify the costs for various industries. Unfortunately, there does not appear to be a comprehensive study that specifically targets the aerospace / defense industry. Applying the results of the several other industry studies to the defense industry is instructive, however.

Figure 3 shows studies done for the automotive, electronics, industrial facilities construction, and process manufacturing (chemical) industries.

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<table>
<thead>
<tr>
<th>Industry</th>
<th>Reported Potential Cost Avoidance for This Industry</th>
<th>Cost Avoidance as Applied to Each $100B of Defense Acquisition</th>
<th>Cost Avoidance if AME Were in Place at Inception of Current 98 Major Weapon System Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. Automotive (Inadequate Interoperability)</td>
<td>$1.05B costs on $288.7B revenues = 0.364 % of revenues</td>
<td>$364 million</td>
<td>$4.4 billion</td>
</tr>
<tr>
<td>U.S. Automotive (Inadequate Infrastructure for Supply Chain Integration)</td>
<td>1.25% of shipments</td>
<td>$1.25 billion</td>
<td>$15.2 billion</td>
</tr>
<tr>
<td>U.S. Electronics (Inadequate Infrastructure for Supply Chain Integration)</td>
<td>1.22% of shipments</td>
<td>$1.22 billion</td>
<td>$14.9 billion</td>
</tr>
<tr>
<td>U.S. Industrial Facilities Construction</td>
<td>$15.8B costs on $374B revenues = 4.2% of revenues</td>
<td>$4.20 billion</td>
<td>$51 billion</td>
</tr>
<tr>
<td>Process Manufacturing (Petroleum, Chemical Pharmaceutical)</td>
<td>Improve overall operating efficiency by at least 10%</td>
<td>$7.30 billion</td>
<td>$89 billion</td>
</tr>
</tbody>
</table>

Methodology for Figure 3: The referenced industry studies provide potential cost avoidance estimates that were converted into a percentage of industry revenue. In the third column, those percentages are multiplied by $100 billion to arrive at potential cost avoidance per $100 billion of defense acquisition. In the fourth column, those percentages are multiplied by $1,219 billion to arrive at a hypothetical cost avoidance that could have been achieved had AME practices been in place at the inception of the current 98 major weapon system programs.

Figure 3: Magnitude of Potential Cost Avoidance

21 To calculate the values in columns 3 and 4 for the process manufacturing industry, the 10% savings on “overall operating efficiency” were assumed to be based upon Cost of Goods Sold (COGS) rather than revenues. The ratio of COGS to revenues for companies in this industry is wide-ranging, but the average for representative companies in this group (Dow Chemical, 84%; DuPont, 74%; Eastman Chemical, 75%; Owens Corning, 54%; and Ford 78%) was 73% according to their 2010 annual reports. The 10% savings is multiplied by 73% COGS to estimate savings of 7.3% of revenues.
Each study provides enough information to quantify wasted costs (or in other words, potential for cost avoidance) as a percentage of revenues. Those percentages are shown in the second column. The percentages range from about 0.36% to 7.3%. The wide range of percentages is attributable to the fact that each study: 1) evaluates the costs based on its own definitions of what is to be counted as a cost; 2) evaluates a different industry. The first four industry studies were prepared by Research Triangle Institute for NIST, and the fifth (Process Manufacturing) was prepared by the Smart Manufacturing Leadership Coalition under funding from the National Science Foundation.

In the third column of Figure 3, the percentage of cost avoidance is applied to a hypothetical $100 billion of future defense acquisitions, assuming that AME practices are in place no later than Milestone A of the weapon system acquisition programs. The potential cost avoidance ranges from $364 million to $7.3 billion per $100 billion of defense acquisitions.

In the fourth column of Figure 3, the percentage of cost avoidance is applied to show how many dollars would have been saved if AME practices had been in place at the inception of all 98 major weapon system programs in the DoD portfolio in 2010. The potential cost avoidance ranges from $4.4 billion to $89 billion for this $1.219 trillion (with a “t”) portfolio.

The first three studies (two automotive and one electronics industry study) probably understate the potential savings, because their definitions of cost are more narrow than the costs described by AME. While they include many interoperability costs, they do not seem to include cost of unnecessary design / prototype / test iterations.

The studies targeting industrial facilities construction and process manufacturing use a more broad net for quantifying wasted costs than the other studies, but still not necessarily as broad as the net cast by AME. It is also difficult to say these studies offer an apples-to-apples comparison of costs because there are non-trivial differences between the manufacturing of defense weapon systems (aircraft, ground vehicles, and ships with their leading-edge electronics) and the building of industrial facilities and the production of chemicals.

While none of these studies offers a precise estimate of potential cost avoidance for defense manufacturing, they collectively offer a rough-order-of-magnitude estimate of the cost avoidance opportunity. With this estimate, decision makers can recognize roughly how much cost could be avoided, and can begin to justify government investment and policy changes to capture the available savings.
Industry literature offers several other case studies showing the dramatic cost and time savings that can result from successful implementation of AME practices.

- A presentation by LMI based on work sponsored by the Defense Logistics Agency focused on the use of 3D Technical Data Packages (3D TDPs) that are more complete, interoperable, and better preserved into the sustainment phase of a system’s life cycle. LMI asserts that DLA could avoid costs of $939M per year for consumable spare parts.23 The presentation also asserts that procurement of commodity spare parts without “good tech data” cost 2.1 times more than similar parts with good tech data.

- Procter & Gamble, in collaboration with Los Alamos National Laboratory, developed PowerFactor, a comprehensive system to predict, prevent, and reduce critical manufacturing equipment failures in over 140 plants worldwide. This system of methods, statistical and analytical tools, and simulation software has been used at P&G for the past decade. Benefits include over $1 billion saved by improving system reliability, 30% to 40% improvement in equipment reliability, and 60% to 70% faster startup for new equipment and product initiatives.24

- An IMTI report said that digital characterization is useful in driving manufacturing processes. It also allows rapid optimization in the virtual realm, shortening product development time and delivering products at the right cost for the product and the market. Typical reported results indicate a 50% decrease in the cost and time of transitioning from requirements to production.25

- The IMTI report also said that the possible benefits of intelligent, integrated manufacturing can be projected from those that are already being realized today. In early implementation of model-based methods and tools, product development times are being slashed. For military vehicles, product development cycles of 2 years have been cut to as short as 90 days, with some being delivered in less than 1 month. In the construction equipment industry, one manufacturer touts a reduction in product development time from 27 months to 9 months. The key to these successes is the use of model-based tools. In the 777 aircraft development, Boeing reported product development time savings of 91% and labor cost savings of 71%. BAE Systems reported time savings of seven fold compared to conventional practice. Procter & Gamble documented savings exceeding $1 billion a year by implementing model-based reliability systems.26

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23 “Why Digital Tech Data?” DMSMS 2010 Plenary Panel, Bruce Kaplan, LMI. Download at: 


• A study from Aberdeen Group reported the following benefits of using 3D CAD models:\textsuperscript{27}
  o 3D tools reduce the development cycle by 30-50%.
  o 3D model use reduces non-conformances by 30-40%.
• CIMdata reports the following savings in its “Independent Report on Achieved Benefits and Return on Investments with DELMIA (digital manufacturing) Solutions”:\textsuperscript{28}
  o 10% reduction in overall product design time.
  o 30% savings in tool design.
  o 65% reduction in number of design changes.
  o 15% savings due to improved quality from validation of processes prior to production.
  o 13% savings in overall production cost.
  o 15% increased production throughput.
  o 30% reduction in overall time-to-market.
  o The U.S. Navy reported that the use of DELMIA tools and other processes contributed to over $370 million in total cost of ownership savings for the LPD17 surface ship program.
  o CIMdata asserts that it is reasonable to expect returns on investment of 5/1 to 10/1 when digital manufacturing software is implemented in combination with digital mockup, process re-engineering, process re-engineering, and as a component of an integrated product life cycle (PLM) solution.
• A Kubotek USA survey of 2,800 CAD system users found that 43% of those using history-based CAD systems need to rebuild 3D models from scratch more than 50% of the time in order to complete a design task because it cannot be done using the original 3D model.\textsuperscript{29}

Chapter 3. Communities of Interest

3.1 Introduction

The literature reviewed for this report revealed that most of the manufacturing communities that are addressing the challenges of AME (such as highly distributed manufacturing, high product development costs, small lot sizes, and rapidly changing requirements) seek to address them using one of many different but overlapping communities of interest.

One way to describe these different-but-overlapping communities of interest is to compare AME to the Quality Movement of the 1980s and 1990s. The Quality Movement included many different but overlapping communities such as Total Quality Management, Re-Engineering, ISO-9000, Six Sigma, 5S, Lean Manufacturing, Just in Time, and Theory of Constraints. Each community had its own keywords and approaches, but the communities still had much in common. Figure 4 illustrates this point, showing the common, overlapping core among Quality Movement communities of interest, with their distinctive features on the outside. The same illustration (on the right, with AME communities of interest as the labels) describes the current AME communities of interest as well. The names and communities have changed; the relationship of overlap is the same.

![Figure 4: Quality Movement Communities of Interest vs. AME Communities of Interest](image-url)
Put another way, current manufacturing communities have developed many different AME-related practices that have much in common. The following table illustrates this point in greater detail by showing several quality movement and AME practices, along with their commonalities in terms of targeted problems, solution strategies, expected benefits, and barriers.

<table>
<thead>
<tr>
<th>Defining Characteristic</th>
<th>Quality Movement</th>
<th>Advanced Manufacturing Enterprise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communities of Interest</td>
<td>• TQM</td>
<td>• Adaptive Vehicle Make (DARPA)</td>
</tr>
<tr>
<td></td>
<td>• ISO-900</td>
<td>• Open Manufacturing (DARPA)</td>
</tr>
<tr>
<td></td>
<td>• Lean Manufacturing</td>
<td>• Factories of the Future Public-Private Partnership</td>
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<td></td>
<td>• 5S</td>
<td>• Intelligent Manufacturing</td>
</tr>
<tr>
<td></td>
<td>• Six Sigma</td>
<td>• Model Based Enterprise; Model Based X; Digital Thread</td>
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<td></td>
<td>• Theory of Constraints</td>
<td>• Network Centric Manufacturing</td>
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<tr>
<td></td>
<td>• Just in Time</td>
<td>• Service Oriented Manufacturing</td>
</tr>
<tr>
<td></td>
<td>• Re-Engineering</td>
<td>• Standards for Interoperability</td>
</tr>
<tr>
<td></td>
<td>• Adaptive Vehicle Make (DARPA)</td>
<td>• Smart Manufacturing / Smart Process Manufacturing</td>
</tr>
<tr>
<td></td>
<td>• Open Manufacturing (DARPA)</td>
<td>• Systems 2020</td>
</tr>
<tr>
<td>Common Targeted Problems</td>
<td>• Waste in all its forms</td>
<td>• Product development takes too long, costs too much</td>
</tr>
<tr>
<td></td>
<td>• Unnecessary transport</td>
<td>• Manufacturing not adequately incorporated into design or requirements definition</td>
</tr>
<tr>
<td></td>
<td>• Unnecessary waiting time</td>
<td>• Prototype testing is very expensive</td>
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<tr>
<td></td>
<td>• Long setup times</td>
<td>• Hard to predict or control costs</td>
</tr>
<tr>
<td></td>
<td>• Defects, scrap &amp; rework</td>
<td>• Hard to collaborate and communicate along highly distributed (global) and rapidly changing supply networks</td>
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<tr>
<td></td>
<td>• Inventory costs</td>
<td>• Design &amp; manufacturing data created and lost repeatedly over the product life cycle</td>
</tr>
<tr>
<td></td>
<td>• Bottlenecks</td>
<td>• Very expensive to handle small lot sizes</td>
</tr>
<tr>
<td></td>
<td>• Inconsistency</td>
<td>• Very expensive to handle changes in requirements</td>
</tr>
<tr>
<td></td>
<td>• Product development takes too long, costs too much</td>
<td>• Hard to understand and manage risk</td>
</tr>
<tr>
<td></td>
<td>• Manufacturing not adequately incorporated into design or requirements definition</td>
<td>• Excess waste materials and energy use</td>
</tr>
<tr>
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<td></td>
<td>• Very expensive to handle changes in requirements</td>
<td>• Design &amp; manufacturing data created and lost repeatedly over the product life cycle</td>
</tr>
<tr>
<td>Common Solution Strategies</td>
<td>• Processes: document, measure, control, and improve them</td>
<td>• Develop modeling tools to enable better designs and decision making, and reduce the need for physical prototyping and testing</td>
</tr>
<tr>
<td></td>
<td>• Visual cues</td>
<td>• Increase interoperability of software for data exchange</td>
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<tr>
<td></td>
<td>• Mistake proofing</td>
<td>• Implement better 3D Technical Data Packages</td>
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<tr>
<td></td>
<td>• Less inventory</td>
<td>• Develop methods for intelligent manufacturing, enabling two-way communication and feedback loops throughout the supply network and over the full system life cycle</td>
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<tr>
<td></td>
<td>• Smaller batches</td>
<td>• Develop methods to improve supply network integration and management</td>
</tr>
<tr>
<td></td>
<td>• Problem-solving teams</td>
<td>• Develop methods for manufacturing that are more adaptable to changing product requirements</td>
</tr>
<tr>
<td></td>
<td>• Continuous improvement</td>
<td>• Develop tools to enhance trusted systems and cyber security</td>
</tr>
<tr>
<td></td>
<td>• Worker training</td>
<td>• Adopt open standard interfaces for better interconnectivity and interoperability</td>
</tr>
<tr>
<td></td>
<td>• Develop modeling tools to enable better designs and decision making, and reduce the need for physical prototyping and testing</td>
<td>• Lower cost</td>
</tr>
<tr>
<td></td>
<td>• Increase interoperability of software for data exchange</td>
<td>• Faster throughput</td>
</tr>
<tr>
<td></td>
<td>• Implement better 3D Technical Data Packages</td>
<td>• Higher conformance to requirements</td>
</tr>
<tr>
<td></td>
<td>• Develop methods for intelligent manufacturing, enabling two-way communication and feedback loops throughout the supply network and over the full system life cycle</td>
<td>• Competitive advantage to best practitioners</td>
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<tr>
<td></td>
<td>• Develop methods to improve supply network integration and management</td>
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<td>• Adopt open standard interfaces for better interconnectivity and interoperability</td>
<td>• Competitive advantage to best practitioners</td>
</tr>
<tr>
<td>Common Benefits</td>
<td>• Lower cost</td>
<td>• Lower cost</td>
</tr>
<tr>
<td></td>
<td>• Faster throughput</td>
<td>• Faster throughput</td>
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<td>• Higher conformance to requirements</td>
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<td>Defining Characteristic</td>
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<td>-------------------------</td>
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<td>-----------------------------------</td>
</tr>
</tbody>
</table>
| Common Barriers         | • Lack of senior management champions / support  
• Perception of high cost  
• Resistance to change | • New technology development and implementation required  
• Open collaboration raises concerns regarding intellectual property and national security  
• Hard to reach consensus on industry standards  
• Parochial motivations: some key players seek to maintain their competitive advantage by favoring proprietary interfaces over open standards  
• Extremely complex products/systems with frequently changing requirements  
• Goal of maintaining technical data over full product life cycle challenged by issues regarding ownership of the data rights  
• DoD business & contracting practices; funding uncertainty & instability  
• Shrinking skilled workforce; lack of STEM students  
• Resistance to change |

There are many AME communities of interest. For this report, a “community of interest” is defined as: “A group of industry, government, and academic professionals who share a set of targeted problems, proposed solutions, expected benefits, and barriers to implementation. They may or may not actually be working together.”

The more one looks, the more communities one finds. Some communities are bound by a formal organization that has regular meetings and publishes collaboratively. Some “sub-communities” have been grouped together into a single community of interest even if those sub-communities do not actively collaborate. Some communities of interest are relatively mature, while others are just getting started. Not many success stories can be told yet, and they are generally not mature enough to have “best practices” in place yet.

The communities of interest studied for this report are the following.

• DARPA Adaptive Vehicle Make Program  
• DARPA Open Manufacturing Program  
• Factories of the Future Public-Private Partnership (ICT Sub-Domain)  
• Intelligent Manufacturing  
• Manufacturing Enterprise Modeling and Simulation  
• Network Centric Manufacturing  
• Smart Manufacturing  
• Service Oriented Manufacturing  
• Standards for Interoperability  
• Systems 2020
3.2 Analytical Framework for This Study

Dr. Michael McGrath of Analytic Services, Inc., and a member of the Advisory Panel for this report, encouraged the team to use this classic approach to identifying investment areas for AME:

- Define the current state of defense manufacturing
- Define the desired future state of defense manufacturing
- Identify the gaps that must be addressed to get to the desired future state.

With a topic as broad and deep as AME, this is a difficult task. Fortunately, the AME communities of interest each have experts working on the front lines who have already been thinking and writing about the current state, the future state, and the gaps for a few years. The literature review included the following:

- Over 470 briefings, papers, and articles were initially gathered.
- About 320 of them were selected as most relevant, and mined for information.
- About 70 documents were cited in the final report.

The study team’s analytical approach was to:

- Study these documents and talk to subject matter experts;
- organize the information into:
  - communities of interest
  - targeted problems
  - solution strategies
  - expected benefits
  - barriers to implementation;
- analyze the information and identify/extract/document common themes;
- consolidate their solution strategies into recommended areas for DoD leadership and investment.

Using this analytical approach, the team identified over 100 solution strategies from the referenced sources, and organized them into seven recommended areas for DoD investment. Those recommendations are summarized in Chapter 6 and described in detail in Chapter 4.

One of the strengths of the study team’s approach was that the research was largely based on “published” sources. Almost all of the sources are conference briefings or proceedings, or formal papers published by government or industry organizations. The sources were thoroughly reviewed prior to publication, so readers can be confident that they accurately present the intended message. The sources can be referred back to for their original context. This is in contrast to personal interviews, which may depend on “off the cuff” answers and the inevitable distortion that comes from an interviewer trying to transform handwritten notes into a meaningful narrative.
This report is designed for an audience that likes to see the data. Therefore, Chapter 3 has descriptions of each community of interest that use lengthy quotations from the source documents so that each community is described largely in its own words. Furthermore, each community of interest description includes a table that shows excerpts – usually taken verbatim – from the source documents in order to present the data without distortion. Most of the referenced documents are either downloadable from the Internet links given, or available by request from the referenced source’s authors. Readers are therefore able to obtain the referenced documents themselves, and interpret the excerpts in their original context.

The following sections briefly describe each community of interest and show the targeted problems, solution strategies, benefits, and barriers to implementation for each.

3.3 DARPA Adaptive Vehicle Make (AVM) Program

According to a September 2010 DARPA news release, “agile and flexible design and manufacturing approaches are needed to meet the demands of rapidly changing threats to national security, declining defense budgets and the increasing complexity of systems. Current approaches to the development of defense systems and vehicles have proven inadequate for the timely delivery of much needed capability for the warfighter. The Defense Advanced Research Projects Agency (DARPA) launched a portfolio of programs aimed at dramatically compressing development timelines for complex defense systems. DARPA’s Adaptive Vehicle Make (AVM) portfolio will fundamentally alter the way systems are designed, built and verified, significantly improving the capacity to handle complexity—which has been rapidly outpacing existing 1960s-vintage approaches to managing it….”

“The AVM portfolio is composed of four synergistic efforts: META, Instant Foundry Adaptive through Bits (iFAB), Fast Adaptive Next-Generation Ground Combat Vehicle (FANG) and Manufacturing Experimentation and Outreach (MENTOR), which will culminate in the development of a next generation infantry fighting vehicle.”

DARPA’s Adaptive Vehicle Make web site describes these efforts, which are summarized below.

META

The ultimate goal of the META program is to dramatically improve the existing systems engineering, integration, and testing process for defense systems. META is not predicated on one particular alternative approach, metric, technique or tool. Broadly speaking, however, it aims to develop model-based design methods for cyber-physical systems far more complex and heterogeneous than those to which such methods are applied today; to combine these methods with a rigorous deployment of hierarchical abstractions throughout the system architecture; to optimize system design with respect to an observable, quantitative measure of complexity for the entire cyber-physical systems; and to apply probabilistic formal methods to the system verification problem, thereby dramatically reducing the need for expensive real-world testing and design iteration.

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iFAB

iFAB: The Instant Foundry Adaptive through Bits (iFAB) program looks to lay the groundwork for the development of a foundry-style manufacturing capability—taking as input a verified system design specified in an appropriate metalanguage—capable of rapid reconfiguration to accommodate a wide range of design variability and specifically targeted at the fabrication of military ground vehicles. The principal objective of iFAB—coupled with META—is to enable substantial compression of the time required to go from idea to product through a shift in the product value chain for defense systems from "little m" manufacturing (i.e., fabrication) to the other elements of "big M" Manufacturing (i.e., design, customization, after-market support, etc.). The iFAB vision is to move away from wrapping a capital-intensive manufacturing facility around a single defense product, and toward the creation of a flexible, programmable, potentially distributed production capability able to accommodate a wide range of systems and system variants with extremely rapid reconfiguration timescales. The specific goals of the iFAB program are to rapidly design and configure manufacturing capabilities to support the fabrication of a wide array of infantry fighting vehicle models and variants.

FANG

FANG: The Fast Adaptable Next-Generation Ground Combat Vehicle (FANG) program seeks to develop the infrastructure for and conduct a series of design challenges intended to precipitate open source design for a prototype of a next-generation infantry fighting vehicle analogous to the Army’s Ground Combat Vehicle (GCV).

As part of the FANG effort, vehicleforge.mil is focused on generating an open source development collaboration environment and website for the creation of large, complex, cyber-electro-mechanical systems by numerous unaffiliated designers—with the goal of democratizing the design innovation process by engaging several orders of magnitude more talent than the current industry model. The initial phase of the effort will last 12 months and culminate in the operational deployment of vehicleforge.mil. The development of complex software systems has benefitted significantly from the ability to leverage crowd-sourced innovation in the form of open source code development. vehicleforge.mil aims to significantly expand open source collaborative development for defense systems by employing a general representation language—being developed under the META program—that is rich enough to describe a broad range of cyber-electro-mechanical systems, yet formal enough that the system can be “compiled” or verified in some manner when a design change is made to some element or aspect of it.

The FANG program will apply META, iFAB, and vehicleforge.mil capabilities to a series of design challenges of increasing complexity, seeking to leverage fab-less design, foundry-style manufacturing, and a crowd-sourced innovation model and culminating in a complete design and fabrication of an infantry fighting vehicle in the span of one year.

The Manufacturing Experimentation and Outreach (MENTOR) portion of the FANG program focuses on engaging high school-age students in a series of collaborative design and distributed manufacturing experiments. DARPA envisions deploying up to a thousand computer-numerically-controlled (CNC) additive manufacturing machines—more commonly known as
"3D printers"—to high schools nationwide. The goal is to encourage students across clusters of schools to collaborate via social networking media to jointly design and build systems of moderate complexity, such as mobile robots, go carts, etc., in response to prize challenges.

The following table summarizes the DARPA Adaptive Vehicle Make program’s targeted problems, solution strategies, benefits, and barriers to implementation.

<table>
<thead>
<tr>
<th>DARPA Adaptive Vehicle Make Community of Interest Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Targeted Problems</strong></td>
</tr>
<tr>
<td>Current approaches to the development of defense systems and vehicles have proven inadequate for the timely delivery of much needed capability for the warfighter.</td>
</tr>
<tr>
<td><strong>Solution Strategies</strong></td>
</tr>
<tr>
<td>Launch programs to fundamentally alter the way systems are designed, built and verified, significantly improving the capacity to handle complexity.</td>
</tr>
<tr>
<td>Move to higher levels of abstraction in design, introducing design automation and model-based verification and decoupling the design and build phases of the development process.</td>
</tr>
<tr>
<td>META—a program to develop metrics, a representation metalanguage, design tools, and verification techniques to enable the synthesis of vehicle designs that are correct-by-construction.</td>
</tr>
<tr>
<td>META - develop model-based design methods for cyber-physical systems far more complex and heterogeneous than those to which such methods are applied today; to combine these methods with a rigorous deployment of hierarchical abstractions throughout the system architecture; to optimize system design with respect to an observable, quantitative measure of complexity for the entire cyber-physical systems; and to apply probabilistic formal methods to the system verification problem, thereby dramatically reducing the need for expensive real-world testing and design iteration.</td>
</tr>
<tr>
<td>iFAB complements META’s “fab-less” design capability with a “foundry-style” manufacturing approach.</td>
</tr>
<tr>
<td>FANG - Expand the number of contributors in the design process by orders of magnitude—we call this ‘democratizing’ innovation. To that end, DARPA will develop a collaborative infrastructure for crowd-sourcing vehicle designs, called vehicleforge.mil. Investigate novel mechanisms for credentialing users and for ensuring the integrity of the final design.</td>
</tr>
<tr>
<td>FANG will generate an open source development collaboration environment and website for the creation of large, complex, cyber-electro-mechanical systems by numerous unaffiliated designers—with the goal of democratizing the design innovation process by engaging several orders of magnitude more talent than the current industry model.</td>
</tr>
<tr>
<td><strong>Benefits</strong></td>
</tr>
<tr>
<td>Compress development timelines by at least 5X.</td>
</tr>
<tr>
<td>Shift the product value chain toward high-value-added design activities.</td>
</tr>
<tr>
<td>Drastically democratize the innovation process.</td>
</tr>
<tr>
<td>META will create a toolset that enables the development of complex military vehicles and avoids the design-build-test-redesign loop that tends to lead to cost and schedule growth as we chase unanticipated interactions within the system.</td>
</tr>
<tr>
<td>The ultimate goal of the META program is to dramatically improve the existing systems engineering, integration, and testing process for defense systems.</td>
</tr>
<tr>
<td>iFAB will create a bitstream-programmable manufacturing facility that can be rapidly configured to produce a new design or design variation with nearly zero learning curve, resulting in large-scale manufacturing in quantities of one. An iFAB-style facility is the defense industry’s analog to modern integrated circuit manufacturing plants, which are automated, adaptable and capable of producing a broad spectrum of products.</td>
</tr>
<tr>
<td>iFAB is to enable substantial compression of the time required to go from idea to product through a shift in the product value chain for defense systems from &quot;little m&quot; manufacturing (i.e., fabrication) to the other elements of &quot;big M&quot; Manufacturing (i.e., design, customization, after-market support, etc.).</td>
</tr>
</tbody>
</table>
**DARPA Adaptive Vehicle Make**  
**Community of Interest Analysis**

The iFAB vision is to move away from wrapping a capital-intensive manufacturing facility around a single defense product, and toward the creation of a flexible, programmable, potentially distributed production capability able to accommodate a wide range of systems and system variants with extremely rapid reconfiguration timescales.

The FANG program seeks to develop the infrastructure for and conduct a series of design challenges intended to precipitate open source design for a prototype of a next-generation infantry fighting vehicle analogous to the Army’s Ground Combat Vehicle (GCV).

**Barriers to Implementation**

The leap from integrated circuits to an infantry fighting vehicle is not an easy one. The diversity of components and interactions among them is much richer and much more dynamic, and the environment context in which vehicles operate is also significantly more complex.
3.4 DARPA Open Manufacturing Program

The BAA for the DARPA Open Manufacturing Program released in May 2011 describes the program in the following way.\(^{32}\)

“Regardless of whether the product is an electro-mechanical system, a structural component, or a subassembly, the greatest sources of outcome uncertainty are: (a) material and manufacturing variability; (b) manufacturing cost; (c) manufacturing lead times; and (d) component performance range (i.e., whether a component will actually perform as expected). This uncertainty increases risk and drives the cycle of prototype-testing/low-rate production-testing/production-testing that often leads to costly re-designs and delays. Ultimately, this risk raises barriers to innovation and the introduction of new technologies as programs rely on proven (legacy) manufacturing technology and practices.”

“The Open Manufacturing (OM) program seeks to reduce barriers to manufacturing innovation, speed, affordability and predictability of materials, components and subassembly structures in regards to their properties, manufacturability, cost, and schedule. OM plans to invest in: (a) technologies to enable affordable, rapid, adaptable, easily qualifiable, and efficient manufacturing and fabrication processes; (b) comprehensive manufacturing design, selection, simulation, and performance prediction tools; (c) technologies to reduce impediments to accelerated qualification for intended use by establishing capabilities to rapidly and inexpensively characterize, analyze, model, test, and simulate non-linear and/or coupled performance, with guaranteed performance across process variations, environmental conditions, and during service or use; (d) (multi-user) facilities for developing, demonstrating, testing, and hosting new manufacturing processes and process models that offer potential manufacturers access and choices of process selection and “try-before-you-buy” options, thereby reducing entry costs and timelines; (e) mechanisms for easy access and exposure to new processes and best practices through open architecture, collaborative (but not necessarily open source) activities structured to protect intellectual property; and (f) training of the U.S. manufacturing workforce on new processes by providing enhanced training programs and opportunities. Specifically, the program will seek development and demonstration of technologies that reduce impediments to the efficient manufacturing of affordable, competitive products in several specific product/manufacturing domains so that they can be rapidly introduced into service at low fiscal and environmental costs.”

“DARPA seeks to impact this problem in two key ways: (a) develop the technological elements necessary for the reliable production and use of a given product; and (b) demonstrate that it is possible to reduce time-to-product and provide the expected lifetime/capability/readiness knowledge base to enable qualification for intended use in specific examples.”

The program was announced to industry in February 2011,\(^{33}\) and so it was still in its very early stages at the time this report was written.

\(^{32}\) DARPA-BAA-11-54 Open Manufacturing, posted 5 May 2011. Download at: [https://www.fbo.gov/index?s=opportunity&mode=form&id=be4346eff31b9a86d1b5ab8ebfe710af&tab=core&cvie w=0](https://www.fbo.gov/index?s=opportunity&mode=form&id=be4346eff31b9a86d1b5ab8ebfe710af&tab=core&cvie w=0)
The following table summarizes the DARPA Open Manufacturing program’s targeted problems, solution strategies, benefits, and barriers to implementation.

<table>
<thead>
<tr>
<th>DARPA Open Manufacturing Community of Interest Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Targeted Problems</strong></td>
</tr>
<tr>
<td>Developing and manufacturing of low-volume, high-value systems is both expensive and time consuming.</td>
</tr>
<tr>
<td>Many high-profile defense systems have suffered from extensive delays and cost escalation during testing and early production due to difficulties incurred in the course of manufacturing key components and subassemblies.</td>
</tr>
<tr>
<td>Many military platforms have encountered unanticipated problems caused by not having a full understanding of the range of the coupled material/component/subassembly interactions, behaviors and properties of the manufactured articles.</td>
</tr>
<tr>
<td>Loss of manufacturing capability in the U.S.</td>
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<tr>
<td>High cost and long lead times associated with custom parts.</td>
</tr>
<tr>
<td>Difficulty in introducing new technology into service.</td>
</tr>
<tr>
<td>Barriers to entry for small business manufacturing innovators that include high capital and product qualification costs.</td>
</tr>
<tr>
<td>Product qualification methods are cumbersome, time-consuming, and expensive, and they inhibit the rapid introduction of new and improved processes.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Solution Strategies</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing design tools:</td>
</tr>
<tr>
<td>• Develop design &amp; simulation tools that allow rapid predictions of guaranteed performance in actual manufactured products.</td>
</tr>
<tr>
<td>• Create tools that empower fully functional products.</td>
</tr>
<tr>
<td>Rapid manufacturing: Develop new manufacturing/fabrication capabilities and models that:</td>
</tr>
<tr>
<td>• Enable rapid setup and processing.</td>
</tr>
<tr>
<td>• Allow low-volume production runs with the same economies as high-volume runs.</td>
</tr>
<tr>
<td>Rapid qualification: Identify experiments and targeted tests that rapidly optimize part qualification processes.</td>
</tr>
<tr>
<td>Design for testability.</td>
</tr>
<tr>
<td>Manufacturing to need:</td>
</tr>
<tr>
<td>• Provide complete solutions to “the inverse problem” that enable a desired functionality to dictate product attributes.</td>
</tr>
<tr>
<td>• Provide processes and toolsets to enable fabrication of “good enough” parts.</td>
</tr>
<tr>
<td>Manufacturing demonstration facilities: Increase access &amp; expand the base of manufacturing by establishing centers (foundries) that level the playing field, enabling competition of small firms with larger industry.</td>
</tr>
<tr>
<td>Sustainable business models: Establish interface protocols that permit manufactures to seamlessly interface with higher levels of design abstraction and that the manufacturing processes models, tools and behavior models can be fully integrated into integrating libraries.</td>
</tr>
<tr>
<td>Sustainable business models: Streamlined IP process.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Benefits</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce barriers to manufacturing innovation, speed, affordability and predictability of materials, components and subassembly structures in regards to their properties, manufacturability, cost, and schedule.</td>
</tr>
<tr>
<td>Establish tools that: (a) account for and select between manufacturing options and likely outcomes in terms of producibility, quality, cost and probabilistic predictions of short-and long-term performance; and (b) can be exercised and inform the design process at the earliest possible time.</td>
</tr>
<tr>
<td>Development and demonstration of innovative, rapid manufacturing processes and methods to produce high-value, high-margin components in small lot sizes quickly and with unit costs that are competitive with large lot production.</td>
</tr>
</tbody>
</table>

33 “Open Manufacturing Industry Days,” Dr. Leo Christodoulou, Director, DSO, DARPA, February 2011. Download at: https://www.fbo.gov/download/5a4/5a4480ae63cf68fe6d2b3f050d9c5e68/Presentation_1_Leo_Christodoulou.pdf
### DARPA Open Manufacturing
#### Community of Interest Analysis

Development of processes and tools that can be rapidly tailored or reconfigured to produce several different components and/or meet different quality specifications, measurements and constraints to maximize the impact on multiple platforms and applications. These capabilities also help improve return on capital and enhance exploration of a spectrum of market sectors.

Develop and demonstrate novel methods to reduce the barriers (cost, schedule, and technical risk) to qualifying/validating new processes, while at the same time quantifying the level of risk. Develop methods to qualify a component made by new, different or previously unqualified materials or processes in less than 50 percent of the time required by current, traditional methods (build and break) – and at less than 50 percent of the cost using current, traditional methods (build and break) as a benchmark.

### Barriers to Implementation

The referenced sources do not specifically identify the barriers to implementation. As a DARPA program, it can reasonably be asserted that the program takes on high technical risk, and therefore the success of individual projects are highly uncertain.
3.5 Factories of the Future Public-Private Partnership (ICT Sub-Domain)

The Factories of the Future Public-Private Partnership (FoF PPP), launched under the European Economic Recovery Plan, addresses the development of the next generation of production technologies. The focus of the FoF PPP initiative is to support collaborative research projects on innovative enabling technologies that benefit many industrial sectors. Project results are expected to be implemented as improvements in production processes shortly after the conclusion of funded projects. The initiative includes four sub-domains:

- Sustainable manufacturing
- Information and Communication Technologies (ICT) Enabled Intelligent Manufacturing
- High performance manufacturing
- Exploiting new materials through manufacturing

This analysis is concerned only with the Information and Communication Technologies (ICT) Enabled Intelligent Manufacturing sub-domain.

The FoF PPP Roadmap says that ICT “aims to improve the efficiency, adaptability and sustainability of production systems and their integration with agile business models and processes in an increasingly globalized industry, requiring continuous change of processes, products and production volumes.” It further explains that ICT is a key enabler for improving manufacturing systems at three levels:

- Agile manufacturing and customization involving process automation control, planning, simulation and optimization technologies, robotics, and tools for sustainable manufacturing (smart factories);
- Value creation from global networked operations involving global supply chain management, product-service linkage and management of distributed manufacturing assets (virtual factories);
- A better understanding and design of production and manufacturing systems for better product life cycle management involving simulation, modeling and knowledge management from the product conception level down to manufacturing, maintenance and disassembly/recycling (digital factories).

According to the roadmap, the investments are funded on a 50/50 basis between public and private contributions. The ICT sub-domain is funded for 30% of the entire 1.2 billion Euro investment, which translates into $516 million (U.S. dollars, using a May 2011 exchange rate). Therefore, the public share of the investment in ICT is about $258 million.

The FoF PPP considers improvement in the ICT sub-domain as imperative for the long-term economic survival of the European Union’s manufacturing sector. The roadmap asserts that,

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“with the growing importance of manufacturing (small and medium enterprises) within the European economy in terms of GDP and number of jobs, increase in competitiveness and production flexibility have become critical aspects for the survival of European manufacturing in the changing and uncertain global scenario.”

The following table summarizes the FoF PPP’s targeted problems, solution strategies, benefits, and barriers to implementation.

<table>
<thead>
<tr>
<th>EU FoF PPP ICT-Enabled Intelligent Manufacturing</th>
<th>Community of Interest Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Targeted Problems</strong></td>
<td></td>
</tr>
<tr>
<td>Too many rejected components and too much raw material used</td>
<td></td>
</tr>
<tr>
<td>High cost and weight of manufactured products</td>
<td></td>
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<tr>
<td>Slow throughput, poor tool and equipment life, insufficient repeatability and accuracy</td>
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<tr>
<td>Too much waste, power consumption, and finishing operations</td>
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<tr>
<td>Too short of a time between required maintenance intervals</td>
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<tr>
<td><strong>Solution Strategies</strong></td>
<td></td>
</tr>
<tr>
<td>Adaptive and fault tolerant process automation, control, and optimization technologies and tools</td>
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<tr>
<td>Intelligent production machines and “plug and produce” connection of automation equipment, robots and other intelligent machines, peripheral devices, smart sensors and industrial IT systems</td>
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<tr>
<td>Large scale testing and validation of robotics-based and other automated manufacturing and post-production automation processes in real-world environments</td>
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<tr>
<td>Novel methods of interaction with, and automatic tasking of, intelligent cooperative automation and robotic control systems that support flexible, small batch and craft manufacturing</td>
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<tr>
<td>Laser applications, including ultra-short pulse lasers and adaptive and dynamically-controlled laser-based materials processing systems</td>
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<tr>
<td>New metrology tools and methods for large-scale and real-time handling and processing of manufacturing information</td>
<td></td>
</tr>
<tr>
<td>Enabling technologies under the emergent Internet of Things, meaning a network of devices such as RFID, wireless sensor networks, and machine-to-machine communication, significantly contributing to increased logistics efficiency, real-time monitoring of material flows and resource use</td>
<td></td>
</tr>
<tr>
<td>Tools supporting the production of smart industrial goods, allowing advanced maintenance technologies and services such as predictive and remote equipment maintenance simultaneously and across different sites</td>
<td></td>
</tr>
<tr>
<td>Integrated product/service systems</td>
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<tr>
<td>Real-time asset management methods for materials and high tech commodity costs, routings, and inventories</td>
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<tr>
<td>Comprehensive engineering platforms that enable cross-disciplinary information sharing and the capture and transfer of industrial design knowledge</td>
<td></td>
</tr>
<tr>
<td>More intelligent models providing details of design intent, as well as with better predictive capabilities to help reduce the need for physical prototyping and the erection of pilot plants.</td>
<td></td>
</tr>
<tr>
<td>Self-organizing, collaborative design environments able to adapt to the needs of different sectors and industries, including facilities for product modeling, decision making, and client-oriented simulation</td>
<td></td>
</tr>
<tr>
<td>Improved tools for life cycle management of all design information and analysis results</td>
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<tr>
<td><strong>Benefits</strong></td>
<td></td>
</tr>
<tr>
<td>Flexible, short cycle time</td>
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<tr>
<td>Variability controlled manufacturing capability</td>
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<tr>
<td>Energy efficient manufacturing</td>
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<tr>
<td>Reliable manufacturing processes</td>
<td></td>
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<tr>
<td>Cost effective production</td>
<td></td>
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<tr>
<td>Faster set-up/ramp-up</td>
<td></td>
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<tr>
<td>Have a direct, positive economic impact on innovation and research in manufacturing. Improve the competitive position of the European Union’s small and medium manufacturing enterprises in the global market, creating jobs and wealth.</td>
<td></td>
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<tr>
<td>Barriers to Implementation</td>
<td></td>
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<tr>
<td>----------------------------</td>
<td></td>
</tr>
<tr>
<td>Complexity of production systems for low cost products</td>
<td></td>
</tr>
<tr>
<td>Product lifecycle management tools market is dominated by “island” solutions</td>
<td></td>
</tr>
<tr>
<td>Complex products (such as avionics) require thorough testing at early digital prototype stage, requiring drastically improved accuracy, reliability and speed of products/process simulation techniques</td>
<td></td>
</tr>
</tbody>
</table>

34 The Roadmap does not speak much to barriers to implementation. Many barriers can be surmised for such a large undertaking, such as the scope and complexity of the effort, and the need for broad collaboration. Riemenschneider speaks to some barriers in his briefing, “Factories of the Future PPP – Perspectives in the ICT Theme,” APMS International Conference, October 2010. Download at: [http://www.apms-conference.org/images/uploaded/FoF-ICT-WP2011-12%20APMS_11Oct10%20Riemenschneider.pdf](http://www.apms-conference.org/images/uploaded/FoF-ICT-WP2011-12%20APMS_11Oct10%20Riemenschneider.pdf)
3.6 Intelligent Manufacturing

In this Intelligent Manufacturing community of interest section, the following sub-communities are discussed.

- Intelligent and Integrated Manufacturing
- Intelligent Machining
- Smart Assembly
- Smart Machine Platform Initiative

There is little or no coordination between these sub-communities, but their areas of concern overlap enough to treat them as a single community of interest.

Intelligent and Integrated Manufacturing

The National Science and Technology Council’s Interagency Working Group (IWG) on Manufacturing R&D defines intelligent and integrated manufacturing as:

The application of advances in software, controls, sensors, networks, and other information technology to achieve:

- Rapid, cost-predictive development of innovative products and processes
- Highly productive, safe, and secure production machines and systems that are easily adapted and reconfigured in response to changing conditions and new opportunities
- Optimized, agile, and resilient enterprises and supply chains.\(^{37}\)

The IWG says, “the area is broad in scope; it encompasses mid- to long-term R&D in support of essentially all manufacturing-specific applications of computers and software. The overall objective is to enable and encourage applications that can significantly improve the production, interorganizational, and business capabilities of U.S. manufacturers, regardless of the size of their firms or where they reside in the supply chains and collaborative, networked enterprises of the future. Advances in integrated and intelligent manufacturing capabilities will enable companies to optimize knowledge, technology, and talent to achieve sustainable competitive advantages.”

Indeed, IWG defines a broad umbrella in its discussion of Intelligent and Integrated Manufacturing. It may even be as broad as the AME umbrella. The IWG’s discussion of one topic, “Intelligent Systems for Manufacturing Processes and Equipment,” overlaps most closely with the other sub-communities within the Intelligent Manufacturing community of interest. An excerpt of IWG’s discussion of Intelligent Systems for Manufacturing Processes and Equipment follows.

“The continuing exponential growth of computing power and the increasing availability of inexpensive, wireless, and networked sensors will soon deliver the technological horsepower required to build intelligent manufacturing processes and equipment with the ability to:

- Know and communicate their capabilities, condition, and operational status
- Continually monitor, diagnose, and optimize all essential process parameters and their own performance
- Perform self-calibration and predict preventive maintenance tasks
- Know the quality of their work and can take steps to improve it
- Automatically capture, classify, and catalog process knowledge
- Flexibly build many variations of products in small, mixed quantities
- Discern patterns and trends that are beyond what humans can manage, and recommend appropriate responses to assist manufacturing knowledge workers in responding to complexity
- Be energy efficient and environmentally friendly
- Enhance worker safety and allow intuitive and robust human interaction

The technologies targeted for development in this category of R&D activities would make the leap from the predictive design capabilities discussed in the previous section to actual manufacturing process performance on the plant floor. Because the technologies envisioned here would possess the equivalent of a learning capacity, the results of data gathering, information analysis, and the resulting lessons “learned” would be used to inform future process designs and plans.”

Another extensive discussion of intelligent, integrated manufacturing systems (IIMS) is IMTI’s “Intelligent, Integrated Manufacturing Systems.” Like the NSTC IWG, IMTI defines a broad umbrella. IMTI describes the attributes of an IIMS by saying that an IIMS will:

- Autonomously sense and understand the current production environment (everything from product specifications to supply chain capabilities),
- Determine the information required for successful operation and decision-making, and then acquire and integrate that information from internal and external systems,
- Autonomously make needed decisions and control the manufacturing processes and associated business operations of the enterprise,
- Detect and correct operational deviations from expected results,
- Learn from experience and update underlying models to reflect an improved understanding of reality,
- Generate and manage all the manufacturing information needs, from product and process details through enterprise business and operational processes, and
- Provide information on demand in a suitable format and at the appropriate level of detail to all requesting individuals and functions.

IMTI also describes how today’s best manufacturing operations software is inaccessible to small and medium enterprises in today’s more highly distributed supply networks, limiting the integration and agility of supply networks.

“Manufacturing operations management (MOM) has advanced tremendously over the last several decades. These advances include product and process design, planning and control functions, and operation and improvement of manufacturing processes. The concept of the manufacturing enterprise now includes closely linked supply chain partners. Software tools that aid product design and help plan and control manufacturing execution are widely used. However, the current generation of software solutions is still not based on the emerging manufacturing operations and process standards. They tend to be disparate, stand-alone systems that have different data models and transactions sets, and so lead to inflexible and expensive customized integration. The current generation of software and legacy systems is the primary barrier to adaptive processes being a reality. The large, expensive manufacturing systems of the 1970s and 1980s required a priesthood of expert programmers “above the shop floor” to make those systems work. Those systems’ lack of agility and the inability to fit the scale and budgets of small businesses limited their use and value. In the systems of tomorrow, standardized and friendlier software must allow individual engineers to produce part manufacturing and process execution programs routinely, from their desktops.”

IMTI paints the following broad vision for IIMS (edited here for length).

“The Intelligent, Integrated Manufacturing System will sense and understand the current production environment automatically. This includes everything from the product specifications to available supply network capabilities. The IIMS will assess the currently available information and determine any additional information required for successful operation. The system will then acquire and integrate information from multiple systems or sources (both internal and external) to enable decision-making and control of manufacturing processes and associated business operations of the enterprise and its suppliers. Autonomy is the norm of the IIMS, with the human in the production control loop only for non-routine conditions or situations beyond the bounds of system knowledge.”

“As the IIMS performs production operations, it continuously monitors events and compares real-time measurements to expected values based on experience and predictive models. When deviations occur, the IIMS detects and assesses the deviations to either take corrective action (e.g., reconfiguring processes or product specifications), or to “learn” from the events and update the models to reflect improved understanding of reality. This is based on real-time status knowledge of all production resources (facilities, equipment, personnel, and materials (raw, in process, finished) and the in-process orders and the demand state of the supply network.”

“Each of the intelligent models in the IIMS owns, maintains, and protects its own data. The intelligent model knows how to ask other models for the information it needs for its own

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function, and distributes data to other models for their use at the level of detail required and allowed. In the full realization of the IIMS vision, text and data mining systems, and knowledge discovery, coupled with intelligent processing capability will negotiate common exchange protocols where standards do not resolve differences.”

“During these operations, the IIMS generates and manages all of the manufacturing information needed, from product and unit process details through the full production load and related enterprise business processes. The “learning chain” extends all the way to the strategic planning and management functions of the enterprise. The IIMS will understand and represent information in order to assess the needs and security privileges of all requesting functions and to provide information responses at the appropriate level of detail.”

“The IIMS adds information, knowledge, and additional model fidelity to the development process through each step of the operation. Hence, product and process development becomes a learning environment in which the model set is enriched since it is fully connected to the shop floor and the enterprise. At the point of production operation, the models are rich enough that they become the actual work process controller, distributing to a hierarchy of nodes and decision points all of the information needed for intelligent operation. As the products are made, information continues to flow between processes, to higher-level processes, and to the strategic and enterprise functions. The mature IIMS is a self-diagnosing, self-maintaining system.”

Intelligent Machining

Benét Laboratories is leading an OSD and Army ManTech effort to advance intelligent machining capability. 40 Benét’s Next Generation Machining Vision is described this way:

- On the Shop Floor:
  - Develop, validate, demonstrate, and/or employ the enabling technologies necessary to allow manufacturing equipment to make decisions based upon acquired knowledge to produce the first and every subsequent part and part feature to specification without unscheduled delays or human intervention.
- Above the Shop Floor:
  - Capture what we know and reuse that knowledge.
  - Establish a system that integrates software used to plan and verify manufacturing processes with process knowledge.
  - Optimization of process planning, selection of preferred tools, optimized tool paths and capable machines to reduce cycle time, determine “should costs,” and achieve repeatable quality.

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Assist designers to predict and improve producibility of parts. Provide capability to select features, dimensions, and tolerances to more efficiently and cost effectively produce parts.

Gilson describes a culture shift towards an intelligent manufacturing vision that includes Knowledge Driven Manufacturing Systems, intelligent planning, and smart machining.

Smart Assembly

Austin Weber, in Assembly Magazine, wrote about Smart Assembly, quoting representatives from General Motors, University of Michigan, Boeing, NIST, Proctor & Gamble, and ARC Advisory Group. The article is a brief overview of recent and planned smart assembly efforts by commercial industry. Excerpts from Weber’s article are below.

Smart assembly is a concept that integrates production processes, people, equipment and information using both real and virtual methods to achieve dramatic improvements in productivity, lead time and agility. It goes well beyond traditional automation and mechanization to exploit the effective collaboration of man and machine in engineering and in operations. It integrates highly skilled, multidisciplinary work teams with self-integrating and adaptive assembly processes.

A smart assembly system can adjust and adapt itself to respond to changes in the production environment, such as variability of incoming parts and components. The biggest benefit is robust performance to ensure quality and throughput. Smart assembly elements have already been applied to some production tools, such as fixtures, inspection systems and robots, but we still need more research at the systems level to make machines and subsystems work together. In addition, we need to make advanced technology more affordable to small- and midsized manufacturers.

In the near future, Boeing engineers envision a widespread system that automates the movement of information between digital design tools and wireless production floor systems. Smart assembly applied to these processes will focus on creating intelligent tooling that doesn’t require operators to set limits or torques for a specific operation. Boeing assemblers will refer to work instructions that are projected onto the wing or fuselage of an aircraft. Sensors embedded in fastening tools will guide assemblers, while laser images projected onto the airplane will automatically tell them where to position the correct part.

Electronic measurement and inspection systems will monitor and relay in-process information about every aspect of the assembly process. For instance, sensors will constantly monitor the performance of fastening tools, dispensing equipment, jigs, fixtures and other production equipment.

Other key components are future intelligent manufacturing systems that address agility, responsiveness and simulation; affordability and sustainability; frontiers of manufacturing science, such as nanotechnology and self-assembly; and future manufacturing enterprise that addresses collaboration across complex, reconfigurable supply chains.

Today, most smart assembly activity is focused on digital manufacturing and virtual production (DM/VP) technology. Reducing the time and cost of product launch remains one of the biggest challenges for manufacturers. Many production system problems are not discovered until late in the design-implementation process, which introduces delays and costs.

Proctor & Gamble is on the cutting edge of adopting DM/VP technology. “Unquestionably, the biggest benefit to DM/VP is speed-to-market,” says Tim Storer, P&G’s digital manufacturing product manager. “This benefit can emerge from several different sources, from accelerated validation to reuse of design knowledge to fewer prototype iterations. Ultimately, this allows firms to compress the delivery cycle without sacrificing quality.” According to Storer, one of the key capabilities of DM/VP technology is real-time validation of design. “Models running in the background are able to analyze the current cross-functional design and flag issues before the design is complete,” he explains. “This allows knowledge-based decisions to be made as early as possible in the design cycle.

“DM/VP integrates mechanical, electrical and control systems by sharing common data in a neutral format or database,” adds Storer. “Accordingly, exchange of information is performed in real-time rather than during a discrete validation event.”

Development methods that facilitate conceptualization of a system early in the design process and track functional requirements with the implementation are essential to reducing time to market. To address that need, we’re seeing the emergence of new software platforms that go beyond traditional product lifecycle management (PLM) programs. They bring together multiple elements, including virtual commissioning, and a closed-loop synchronization between physical production systems and upstream product design.
**Smart Machine Platform Initiative**

The vision of the Smart Machine Platform Initiative is to: “develop, validate, and demonstrate the enabling technologies necessary to allow manufacturing equipment to make decisions based upon acquired knowledge to produce the first and every subsequent part and part feature to specification without unscheduled delays or human intervention.”

Administrative oversight for the SMPI is provided by Benét Labs with funding provided through ARDEC, and technical management is provided by Techsolve. The Initiative published its original Technology Resource Plan in 2004, and then updated it in 2010. The updated plan recommends 15 projects for investment, including MTConnect standards development activities. The SMPI Technology and Resource Plan defined ten development thrust areas with examples, as follows.

<table>
<thead>
<tr>
<th>Thrust Area</th>
<th>Examples</th>
</tr>
</thead>
</table>
| On-Machine Part Verification | • Check parts on the machine  
• Self-calibration to interpret probing results  
• System insects and certifies features and characteristics  
• Be able to tell if the machine is doing what it was told to do  
• Machine capable inspection |
| Process Modeling, Planning, and Optimization | • Process models  
• Special-cause process modeling  
• Cutting tool models & optimization  
• Machine determines and optimizes process parameters  
• Pick feeds and speeds without needing a person to do it  
• Feature and physics based modeling  
• Feature based automatic programming |
| Machine Diagnostics and Reporting | • Machine health monitoring  
• Self-diagnostic sensor-integrated “smart” spindle  
• Monitor critical machine characteristics, self-diagnose  
• Uptime monitor and reporting |
| Developing standards |  |
| Cost Estimating: | • Estimating Systems  
• Model Based Cost Estimating |
| Knowledge Capture and Use | • Integrate knowledge and method to implement optimized processes  
• Knowledge and rules capture and use |
| Intelligent Adaptive Equipment | • Sensors that optimize man / machine interface  
• Adaptive tool path feed & speed  
• Machines that adapt to part and process variation, real time  
• Real-time machine performance monitoring and correction  
• Real-time closed loop control (geometry driven)  
• SMPI operating system  
• Machine baselining (performance characterization)  
• Identification of corrective actions using machine-learned knowledge  
• Machine “learning”  
• Translate machine performance parameters into expected error boundaries |
| In-Process Data Collection and Reporting | • Automatic data collection, calculation and metrics reporting  
• Collect data, analyze, initiate and report required activities and performance  
• Monitor key machine characteristics to ID and anticipate failures |
| Specific machines for specific projects |  |
| Integration Framework / Architecture | • Linkage of manual and machine processes  
• Product flow management  
• Links to suppliers  
• Smart networks  
• Seamless info and data exchange (interoperability) |

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The following table summarizes the Intelligent Manufacturing community’s targeted problems, solution strategies, benefits, and barriers to implementation. These are drawn from the following sources.

- “Next Generation Machining and Technology,” Dave Gilson, (Gilson)
- “Assembly Automation: Smart Assembly,” Austin Weber (Weber)
- National Science and Technology Council’s Interagency Working Group (IWG)

<table>
<thead>
<tr>
<th>Intelligent Manufacturing Community of Interest Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Targeted Problems</strong></td>
</tr>
<tr>
<td>Above the Shop Floor / Model-Centric Designing</td>
</tr>
<tr>
<td>- Lack of master models to serve as input for Modern CAM Software</td>
</tr>
<tr>
<td>- Continuous re-creation of geometric models from master 2-D drawings (Gilson)</td>
</tr>
<tr>
<td>Intelligent Planning</td>
</tr>
<tr>
<td>- Difficulty in programming on-machine probing cycles on large, multi-axis machine tools where parts are large and tolerances loose on legacy weapon systems such as Bradley.</td>
</tr>
<tr>
<td>- Lack of generic kinematic models for legacy machine tools or tailored models for all machine tools (Gilson)</td>
</tr>
<tr>
<td>On-Machine Metrology</td>
</tr>
<tr>
<td>- Inability to quickly find datum surfaces on large, heavy, welded structures.</td>
</tr>
<tr>
<td>- Still a lack of in-process verification methods to accurately monitor machining process (Gilson)</td>
</tr>
<tr>
<td>Dimensional Verification</td>
</tr>
<tr>
<td>- For high tolerance parts remounting and reset-up of parts is time consuming and error prone</td>
</tr>
<tr>
<td>- On-machine verification - acceptance of parts (Gilson)</td>
</tr>
<tr>
<td>Supervisory System / Intelligent Maintenance</td>
</tr>
<tr>
<td>- Inability to communicate across the shop floor or to access machine controllers due to either proprietary architecture or proprietary code</td>
</tr>
<tr>
<td>- Inability to validate the G-code and machining process above the shop floor (Gilson)</td>
</tr>
<tr>
<td>State of the art in predictive modeling of machining operations is severely limited; there is no confidence that model results are correct. Making accurate measurements under conditions that mimic extreme temperatures and material deformation rates encountered in machining is challenging. (IWG-pg 63)</td>
</tr>
<tr>
<td>Weapon system development lead times have grown to the point where US forces may be deprived of capabilities that the latest technology offers. For example, the avionics for a new aircraft is two generations behind the current electronics state of the art by the time the system is first deployed. (IWG- pg 64)</td>
</tr>
<tr>
<td><strong>Solution Strategies</strong></td>
</tr>
<tr>
<td>Standardization of 3D MBE requirements. (Gilson)</td>
</tr>
<tr>
<td>Creation of model centric, robust Tech Data Package. (Gilson)</td>
</tr>
<tr>
<td>Producibility reviews early in the process. (Gilson)</td>
</tr>
<tr>
<td>Building a manufacturing knowledge base for designers: best practices; machine capability / availability; tooling database; vendor database. (Gilson)</td>
</tr>
<tr>
<td>Paperless and seamless data transfer system. (Gilson)</td>
</tr>
</tbody>
</table>

## Intelligent Manufacturing

### Community of Interest Analysis

<table>
<thead>
<tr>
<th>Standards for storing and sharing information. (Gilson)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using standardized CAD/CAM packages. (Gilson)</td>
</tr>
<tr>
<td>Use of on and off the machine inspection / Networked CMM data. (Gilson)</td>
</tr>
<tr>
<td>Appropriate training where it is needed. (Gilson)</td>
</tr>
<tr>
<td>Process models and simulation. (IWG-pg 58)</td>
</tr>
<tr>
<td>Scientific and engineering databases. (IWG-pg 58)</td>
</tr>
<tr>
<td>Test and measurement methods. (IWG-pg 58)</td>
</tr>
<tr>
<td>Technical bases for both physical and functional interfaces between the components of systems technologies. (IWG-pg 58)</td>
</tr>
<tr>
<td>Predictive tools for integrated product and process design and optimization. Physics-based models that reliably predict the behavior of manufacturing processes. (IWG-pg 63)</td>
</tr>
<tr>
<td>Intelligent systems for manufacturing processes and equipment. (IWG-pg 66)</td>
</tr>
<tr>
<td>Automated integration of manufacturing software. (IWG-pg 68)</td>
</tr>
<tr>
<td>Secure manufacturing systems integration. (IWG-pg 69)</td>
</tr>
<tr>
<td>Intelligent tools are needed so that designers can predict the impact of their design approaches on key process and performance attributes, including manufacturing, operation, maintenance, replacements, and environmental impacts. These tools need to show total costs in relation to changes in requirements, so different “what if” scenarios can be explored. Smart tools are needed to aid development of tooling and production strategies. (IWG-pg 64)</td>
</tr>
</tbody>
</table>

### Benefits

| Integration of smart technologies into the DoD and US industrial base. (Gilson) |
| Keep full and accurate control of manufacturing scheduling for on-time delivery of critical components. (Gilson) |
| Leverage new technologies and increase domestic capability. (Gilson) |
| Reduce dependence on off-shore sourcing of manufactured components. (Gilson) |
| Faster delivery of critical components to the Warfighter. (Gilson) |
| Speed to market (Weber) |
| Allows knowledge based decisions to be made as early as possible in the design cycle. (Weber) |
| Significantly enhance the efficiency of R&D, design, production and marketing as well as increase returns realized on organizational investments in IT across all supply chain levels. (IWG) |
| The capability to perform process development and qualification through software simulation would greatly reduce tooling costs. Similarly, virtual testing and simulation of as-designed and as-manufactured parts would reduce costs and detect problems without full-systems testing. (IWG-pg 64) |

### Barriers to Implementation

| Technology: standardizing and upgrading software and equipment. (Gilson) |
| Technology: effective knowledge base capture and sharing. (Gilson) |
| Producibility constraints: designer awareness of producibility and match of equipment capability with parts requirements. (Gilson) |
| Training: increased skill development and better approach to resource assignments. (Gilson) |
| Standards and practices: improving and standardizing systems, practices and communication. (Gilson) |
| Accelerated validation / real time validation of design. (Weber) |
| Reuse of design knowledge. (Weber) |
| Fewer prototype iterations. (Weber) |
| Development of these infrastructural technologies often does not bring returns that are easily appropriated by individual private sector organizations that might devote resources to these R&D efforts. (IWG, pg 58) |
3.7 Manufacturing Enterprise Modeling and Simulation

The Manufacturing Enterprise Modeling and Simulation community of interest is both broad and deep. The more one looks, the more one finds additional sub-communities within the larger community. This section will very briefly describe a sampling of the many sub-communities that are practicing or advocating development of manufacturing modeling and simulation. Note that the phrase “Model Based Enterprise” is used by two different sub-communities to describe two somewhat different areas of interest. Further complicating the issue is that “MBE” is used as an acronym for both Model Based Enterprise and Model Based Engineering by different communities. The distinctions are made clear in the respective sections that follow.

Model Based Enterprise (MBE)

A broad definition of MBE was offered by the Next Generation Manufacturing Technology Initiative (NGMTI) in 2005.46

A manufacturing entity that applies modeling and simulation (M&S) technologies to radically improve, seamlessly integrate, and strategically manage all of its technical and business processes related to design, manufacturing, and product support. By using product and process models to define, execute, control, and manage all enterprise processes, and by applying science-based simulation and analysis tools to make the best decisions at every step of the product life-cycle, it is possible to radically reduce the time and cost of product innovation, development, manufacture, and support.

NGMTI’s Strategic Investment Plan for the Model Based Enterprise, quoted above, is a long, detailed document that provides an excellent discussion of many MBE-related concepts. The plan also recommends several areas of investment for the following seven years. The NGMTI web site shows no significant updates after November 2008.47

By 2008, an industry team combined with the NGMTI and PDES, Inc. to continue working towards their shared vision for MBE. This vision included model based engineering, model based manufacturing, and model based sustainment wrapped in the envelope of systems engineering.48 They defined MBE as “An integrated environment that enables multi-disciplinary decision making addressing the entire life cycle.”49

46 “Strategic Investment Plan for the Model-Based Enterprise,” Next Generation Manufacturing Technology Initiative, Page 1-4, 27 May 2005. The NGMTI program was managed by Advanced Technology Institute (ATI) in partnership with the Integrated Manufacturing Technology Initiative (IMTI) and the National Council for Advanced Manufacturing (NACFAM). Download from www.imti21.org at:
47 See the NGMTI web site at: http://projects.ngmti.org/ or http://www.ngmti.org/
49 The industry team identified by Jack Harris (above) included: Rockwell Collins, Lockheed Martin, CostVision, General Electric, Raytheon, Boeing, DNS Innovations, Intelligent Systems Technology, Rolls-Royce, Mechdyne, Siemens, Belean, BAE Systems, CACI, SIS, Information in Place Inc., University of Iowa, University of Kentucky.
In 2010, the JDMTP AME Subpanel described MBE as “building the digital thread.” It states that the MBE challenge is to “drive a continuous flow of integrated design, analysis, and manufacturing information through the product/system life cycle.” The subpanel refers to MBE including advanced modeling and simulation, design optimization tools, virtual prototyping, and data standards efforts.

Model Based Enterprise / 3D Technical Data Packages

An active community that advocates development of the Model Based Enterprise is a collaboration of effort from OSD, Army Research Laboratory, Armament Research Development Engineering Center (ARDEC), Army ManTech, BAE Systems, NIST, and the NIST Manufacturing Extension Partnership (MEP). A Google search for “model based enterprise” most frequently hits web sites, papers, and presentations that can be traced back to representatives of these organizations. Together, these organizations manage a web site called model-based-enterprise.org. This web site defines the Model Based Enterprise as:

A fully integrated and collaborative environment founded on 3D product definition detailed and shared across the enterprise; to enable rapid, seamless, and affordable deployment of products from concept to disposal. Put another way, MBE is a process of reusing the 3D CAD model by all of the downstream customers verses recreating or reentering the data it contains. This model contains all of the information needed to define the product in an annotated and organized manner in order to be read and the information automatically extracted by non-CAD users, thus replacing a traditional drawing.

This community’s definition of MBE places particular emphasis on the 3D product definition, which is communicated through a 3D Technical Data Package (3D TDP). The main purpose of a 3D TDP is to provide all downstream users with a fully annotated 3D model and its associated data elements so that it can be reused effectively without re-mastering the data. This community is particularly concerned with setting standards to define the requirements for 3D TDPs, and with developing tools for validating that model translations from one software package to another are accurate and complete. An excellent discussion of this community’s issues and solutions is in the proceedings of the “Model Based Enterprise Technical Data Packages Summit.”

The NIST Manufacturing Extension Partnership (MEP) program is assisting U.S. small and medium defense manufacturers to transition to MBE-based operations through training and capability assessment opportunities. In a 2009 Supplier Assessment, MEP assessors found

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53 “What is the Status of Digital Data Set, and How to Validate and Certify It?” Paul Huang (Army Research Laboratory) and Simon Frechette (NIST), 2 December 2010, presented at Defense Manufacturing Conference.
54 “Model Based Enterprise Technical Data Packages Summit,” December 15-17, 2009. Not publicly releasable, but available to authorized personnel upon request to Paul Huang, Army Research Laboratory.
56 See summary report at: http://model-based-enterprise.org/MBE_Supplier_Assessment/default.aspx
most suppliers were at level 1, 2, or 3 in the MBE Capability Index for communicating a supplier’s 3D TDP capability, as shown in Figure 5.57

<table>
<thead>
<tr>
<th>MBE Capability Index</th>
<th>No. of Suppliers Assessed at this Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 0 Model Centric Drawings for Design and Manufacturing. Primary Deliverable: 2D Drawing</td>
<td>0</td>
</tr>
<tr>
<td>Level 1 Model Based Manufacturing Primary Deliverable: 2D drawing and neutral CAD model</td>
<td>142</td>
</tr>
<tr>
<td>Level 2 Native CAD Based Manufacturing Primary Deliverable: 2D drawing and native CAD model</td>
<td>143</td>
</tr>
<tr>
<td>Level 3 Model Based Definition Primary Deliverable: 3D Annotated model and light weight viewable</td>
<td>156</td>
</tr>
<tr>
<td>Level 4 Model Based Definition with Data Management Primary Deliverable: 3D Annotated model and light weight viewable via PLM</td>
<td>4</td>
</tr>
<tr>
<td>Level 5 Model Based Definition with Automated Technical Data Package Primary Deliverable: Digital Product Definition Package and TDP</td>
<td>0</td>
</tr>
<tr>
<td>Level 6 MBD with Automated TDP and On Demand Enterprise Access Primary Deliverable: Digital Product Definition package and TDP via the web</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 5: MBE Capability Matrix and Supplier Survey Results

Model Based Engineering / Design

The National Defense Industrial Association (NDIA) Model Based Engineering Subcommittee is chartered to assess and promote model based engineering practices in support of the DoD capability acquisition life cycle. They define model based engineering as, “an approach to engineering that uses models as an integral part of the technical baseline that includes the requirements, analysis, design, implementation, and verification of a capability, system, and/or product throughout the acquisition life cycle.” The models they refer to apply to a wide range of domains, including systems, software, electrical, mechanical, human behavioral, logistics, manufacturing, business, socio-economic, and regulatory. The subcommittee published a final report describing their organization’s activities.58 The report offers 24 recommendations regarding policy and regulations, industry collaboration, standards development, and workforce development.

DoD Modeling & Simulation

The DoD Directive 5000.59 (DoD Modeling and Simulation Management) states that the Under Secretary of Defense for Acquisition, Technology, and Logistics, in coordination with the heads of the DoD components, shall provide a single focal point for the coordination of all matters related to DoD M&S.\(^{59}\)

In February 2009, the Department of Defense Research and Engineering published “The 2008 Modeling and Simulation Corporate and Crosscutting Business Plan.”\(^{60}\) That Plan referenced a DoD strategic vision for modeling and simulation that included the following points:

- **Standards, architectures, networks, and environments that:**
  - Promote the sharing of tools, data, and information across the enterprise
  - Foster common formats
  - Are readily accessible and can be reliably applied by users

- **Policies at the enterprise level that:**
  - Promote interoperability and the use of common M&S capabilities
  - Minimize duplication and encourage reuse of M&S capabilities
  - Encourage research and development to respond to emerging challenges
  - Limit the use of models and data encumbered by proprietary restrictions
  - Leverage M&S capabilities across DoD, other government agencies, international partners, industry, and academia.

- **Management processes for models, simulations, and data that:**
  - Enable M&S users and developers to easily discover and share M&S capabilities and provide incentives for their use
  - Facilitate the cost-effective and efficient development and use of M&S systems and capabilities
  - Include practical validation, verification, and accreditation guidelines that vary by application area.

- **Tools in the form of models, simulations, and authoritative data that:**
  - Support the full range of DoD interests
  - Provide timely and credible results
  - Make capabilities, limitations, and assumptions easily visible
  - Are useable across communities.

- **People that:**
  - Are well-trained
  - Employ existing models, simulation, and data to support departmental objectives
  - Advance M&S to support emerging departmental challenges.

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In addition, the Plan identified three strategic objectives as the core focus for 2010 and beyond:

- Standards: Achieve a set of standards for the development, integration and conduct of DoD modeling and simulation activities.
- Interoperability: Drive towards integrated modeling and simulation tools, data, and services across Department activities.
- Visibility: Facilitate use and reuse of M&S tools, data and services through increased transparency by ensuring access to accurate, authoritative and reliable data.

**Producibility Modeling**

The NDIA Advanced Manufacturing Engineering Capabilities (AMEC) Subcommittee\(^6^1\) is chartered to:

- Promote collaboration between government, industry, universities, associations and consortiums to develop and cultivate advanced manufacturing “engineering” tools, methodologies, and skills;
- Actively support the development and use of modeling and simulation (M&S) tools and approaches to optimize producibility and manufacturing processes during product design and development;
- Advocate the integration of advanced manufacturing “engineering” methodologies into early product design activities that drive a “systems engineering” mindset into the manufacturing sector;
- Drive a manufacturing and production capability mindset into the System Engineering process where preliminary and detailed design trades and decisions are being made;
- Communicate trends and needs for advanced manufacturing “engineering” M&S tools, methodologies, and core competencies for inclusion in strategic plans and roadmaps.

The AMEC committee chair, Dr. Al Sanders of Honeywell, strongly advocates producibility modeling as a key to controlling manufacturing cost and risk.\(^6^2\) He asserts that producibility modeling is usually neglected, and so a key customer input (manufacturing cost requirements) is excluded in the requirements definition process. Dr. Sanders points to a life cycle cost study that found 70% of the life cycle costs are locked in by the time conceptual design is completed, emphasizing that the best chance to make affordability improvements is during concept design.

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An 18-month study by AMEC\textsuperscript{63} revealed the following gaps in current systems engineering practices and design for manufacturing (DFM) analysis capabilities responsible for many of today’s manufacturing and production rate issues encountered in complex aerospace and defense system development programs:

- **Producibility is one of the most neglected “ilities”** due to the lack of validated analytical tools to predict its impact on life cycle cost during early systems engineering and design activities.
- **Inadvertently designed-in producibility issues** drive significant “hidden factory” inefficiencies across the manufacturing enterprise that directly and indirectly impact life cycle production costs.
- **Current DFM tools are inadequate** to predict the fundamental physical mechanisms and design characteristics driving complex aerospace and defense system producibility problems.
- **Producibility M&S is a critical research area** missing from current S&T portfolios with focused research and investments needed to develop new and novel M&S-based analysis capabilities.

A more comprehensive discussion of the NDIA JCSEM M&S Sub-Committee’s work is in their February 2010 final report.\textsuperscript{64} The report suggests the following Producibility and Manufacturing M&S investment areas, in prioritized order, as shown in Figure 6.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure6.png}
\caption{Prioritized Producibility and Manufacturing modeling & simulation investment areas}
\end{figure}

\textsuperscript{63} “21st Century Manufacturing Modeling & Simulation Research and Investment Needs,” NDIA AMEC Committee, May 2011. Download at: 
http://www.ndia.org/Divisions/Divisions/Manufacturing/Documents/NDIAAMECMS.pdf

\textsuperscript{64} “Modeling & Simulation Investment Needs for Producible Designs and Affordable Manufacturing,” Dr. Al Sanders, February 25, 2010. NDIA JCSEM M&S Sub-Committee Final Report. Download at: 
The following table summarizes the Manufacturing Enterprise Modeling & Simulation community’s targeted problems, solution strategies, benefits, and barriers to implementation. These are quoted from the following sources:

- Harris
- Huang & Christensen (H&C)
- Huang & Frechette (H&F)
- the TDP Supplier Summit
- Frechette & Whittenburg (F&W)
- Bergenthal
- Sanders

<table>
<thead>
<tr>
<th>Manufacturing Enterprise Modeling and Simulation Community of Interest Analysis</th>
<th>Targeted Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customers want higher performance at lower cost. (Harris)</td>
<td></td>
</tr>
<tr>
<td>Companies desire organic growth in current market segments with limited cost impact. (Harris)</td>
<td></td>
</tr>
<tr>
<td>Design decisions made in the first 5% of a project determine 70% of the final product cost. (Harris)</td>
<td></td>
</tr>
<tr>
<td>Need to optimize designs for all life cycle requirements. (Harris)</td>
<td></td>
</tr>
<tr>
<td>Need to produce all information automatically to execute enterprise processes. (Harris)</td>
<td></td>
</tr>
<tr>
<td>Need to manufacture products in a virtual environment to predict and solve problems before they occur on the floor. (Harris)</td>
<td></td>
</tr>
<tr>
<td>Need to design for the best total value. (Harris)</td>
<td></td>
</tr>
<tr>
<td>Need to predict overall performance to reduce schedule slips and cost overruns. (Harris)</td>
<td></td>
</tr>
<tr>
<td>Poor quality 3D models cause delays, cost money, and foster a lack of trust. (H&amp;C)</td>
<td></td>
</tr>
<tr>
<td>MIL STD 31000 does not yet clearly define 3D TDPs. 3D model-based concepts have not yet been fully accepted for DoD acquisition. (H&amp;C)</td>
<td></td>
</tr>
<tr>
<td>Lack of automated processes and tools to validate models and build confidence. Results in lost data, significant changes, rework, and unknown change affects design intent. (H&amp;C)</td>
<td></td>
</tr>
<tr>
<td>Lack of properly defined contract requirements for ordering model-based data from industry. (H&amp;C)</td>
<td></td>
</tr>
<tr>
<td>Lack of clear processes for granting appropriate access to data. (H&amp;C)</td>
<td></td>
</tr>
<tr>
<td>Lack of detailed business case means there are no clear steps forward. (H&amp;C)</td>
<td></td>
</tr>
<tr>
<td>Current DoD TDP requirements are focused on 2D, not 3D. (H&amp;F)</td>
<td></td>
</tr>
<tr>
<td>DoD policy and guidance is unclear for TDP requirements for PM/PEOs (H&amp;F)</td>
<td></td>
</tr>
<tr>
<td>MIL-STD-31000 does not clearly define 3D TDPs: contents, user requirements, and delivery formats. (H&amp;F)</td>
<td></td>
</tr>
</tbody>
</table>

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66 “Moving from Drawings to Model-based TDPs: R&D Policies to Practice,” 10 Feb 2011 draft by John Christensen and Paul Huang. Several other AME Subpanel members also contributed to this briefing.

67 “What is the Status of Digital Data Set, and How to Validate and Certify It?” Paul Huang (Army Research Laboratory) and Simon Frechette (NIST), 2 December 2010, presented at Defense Manufacturing Conference.


69 “Certification of 3D Model-Based Enterprise Data,” Simon Frechette (NIST) and Roy Whittenburg (UTRS).


### Manufacturing Enterprise Modeling and Simulation
#### Community of Interest Analysis

| There are no uniform DoD guidelines or standards that define a 3D TDP and specify the content requirements. (H&F) |
| Currently, DoD has no standardized process defining model quality. Without a quality process, there is no way to ensure that the 3D model data being received will work in all downstream processes. Substantial time is lost throughout the product lifecycle due to the need to rework low quality models. (H&F) |
| Many defense systems are delivered with insufficient, inaccurate, and non-interoperable data that makes sustainment difficult. (F&W) |
| 3D model data is not currently approved within DoD for use as the official DoD master product data set. (F&W) |
| There are no approved processes or guidelines within DoD for validating 3D product data integrity or certifying 3D model data for approval as the master data reference. (F&W) |
| Vendors are often reluctant to quote due to risk involved with questionable models or will quote considerably higher prices to cover risk. (F&W) |
| Poor integration of models across the life cycle. There is limited reuse of models between programs. (Bergenthal) |
| Producibility is a forgotten requirement that is hard to quantify early because producibility M&S tools are immature. (Sanders) |
| Need low and high fidelity producibility modeling tools for trade studies to balance performance and producibility. (Sanders) |

#### Solution Strategies

| Develop products in the virtual world. Use state of the art visualization. (Harris) |
| Use net centricity to ensure the availability of managed information at the right place and time, supporting multifunctional decision making and across the extended enterprise. (Harris) |
| Use systems engineering to manage and provide traceability of requirements throughout the life cycle. (Harris) |
| Use information modeling to incorporate standard formats to ensure interoperability of like and cross domain decision making tools and processes. (Harris) |
| Implement 3D modeling and simulation to replace build-test-redesign paradigm with model-test-build paradigm. (Harris) |
| Integrate human factors and ergonomic analysis. (Harris) |
| Connect design efforts to the manufacturing capability. (Harris) |
| Develop ability to fully test “native to neutral” formats across DoD and its trading partners. (H&C) |
| Harmonize DoD efforts with industry efforts to improve model validation. Currently well coordinated with AIA and ASME, but not with SAE and SME or others. (H&C) |
| Update MIL-STD 31000. (H&C) |
| Reach out to industry in order to baseline MBE readiness and raise overall MBE literacy. (H&C) |
| Initiate pilots to demonstrate model-based processes. (H&C) |
| Identify and evaluate existing DoD, industry, and commercial TDP standards and practices. (H&F) |
| Establish current DoD and Agencies policy and guidance for 3D TDPs. (H&F) |
| Recommend DoD level standard or document required for 3D TDP implementation. (H&F) |
| DoD Engineering Drawing and Modeling Working Group (DEDMWG) to revise/update standards related to TDPs. (H&F) |
| Develop and test tools for validating product models. (H&F) |
| Develop an unambiguous set of requirements defining an acceptable level of model quality for use in contractual documents. (H&F) |
| Define the data required to construct the business cases / value propositions, and how that data will be captured. (Bergenthal) |
| Launch a small number of model based contracting pilot projects. (NDIA) |
| Conduct a Grand Challenge project to accelerate the cross-discipline end-to-end model based engineering implementation. (Bergenthal) |
| Explore a model registry concept; assess and shape applicability of M&S catalog and defense meta data standard. (Bergenthal) |
| Conduct consensus conference and develop model based engineering common reference model. (Bergenthal) |
| Develop model based engineering standards roadmap and then develop the standards. (Bergenthal) |
### Manufacturing Enterprise Modeling and Simulation

#### Community of Interest Analysis

#### Benefits

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early and accurate cost estimation. Verified cost models for negotiations and trade studies.</td>
<td>(Harris)</td>
</tr>
<tr>
<td>State of Art visualization improves a team’s decision making ability.</td>
<td>(Harris)</td>
</tr>
<tr>
<td>Discrete Event Simulation validates labor requirements; provides tooling and resource requirements; assesses capacity, cycle time and throughput; evaluates alternative process scenarios; enables optimization of process flow.</td>
<td>(Harris)</td>
</tr>
<tr>
<td>Suppliers can drive their Computer Aided Manufacturing (CAM) software straight from the model, reducing production time.</td>
<td>(TDP Supplier Summit)</td>
</tr>
<tr>
<td>Reduces errors and cost by limiting the number of times an object is re-mastered.</td>
<td>(TDP Supplier Summit)</td>
</tr>
<tr>
<td>Dramatically cuts the time to mission.</td>
<td>(TDP Supplier Summit)</td>
</tr>
<tr>
<td>Allows for increased collaboration and less ambiguity.</td>
<td>(TDP Supplier Summit)</td>
</tr>
<tr>
<td>Clear 3D TDP definition enabling a more streamlined acquisition process, leading to an overall reduction in program lifecycle costs.</td>
<td>(H&amp;F)</td>
</tr>
<tr>
<td>Faster delivery from concept to production.</td>
<td>(H&amp;F)</td>
</tr>
<tr>
<td>Ability to reuse data throughout the product life cycle.</td>
<td>(H&amp;F)</td>
</tr>
<tr>
<td>Easier to use Tech Pubs &amp; Manuals through the availability to reuse 3D models.</td>
<td>(H&amp;F)</td>
</tr>
<tr>
<td>Model validation requirements will result in: a reduction in downstream error rates, thus reducing time to mission; a dramatic increase in the ability to reuse data throughout the product life cycle; clear and consistent expectations between the government and industry.</td>
<td>(H&amp;F)</td>
</tr>
<tr>
<td>Reduce time to acquisition of first article for systems and solutions.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Reduce time to implement planned and foreseen changes in systems.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Enhance reliability by identifying and resolving issues sooner.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Enhance interoperability by including the operating environment and external interfaces in system models, and through continuous interface and interoperability verification.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>More complete evaluation of trade space.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Earlier evaluation of manufacturing feasibility.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Rapidly evaluate changing threats and explore the solution space.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Design reuse.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Lower costs with complex product families.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Earlier risk identification and mitigation.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Early evaluation of manufacturing processes.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Reduced defects and rework costs.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Accelerated development schedule.</td>
<td>(Bergenthal)</td>
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<tr>
<td>Improved system and software reliability and quality.</td>
<td>(Bergenthal)</td>
</tr>
</tbody>
</table>

#### Barriers to Implementation

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaps in modeling and simulation tools exist.</td>
<td>(Harris)</td>
</tr>
<tr>
<td>Interoperability of enterprise tools in an industry problem which hampers performance.</td>
<td>(Harris)</td>
</tr>
<tr>
<td>Lack of advocacy, plan, and schedule for a path forward.</td>
<td>(H&amp;C)</td>
</tr>
<tr>
<td>No current compelling business case for changing policy.</td>
<td>(H&amp;C)</td>
</tr>
<tr>
<td>Currently at a low level of adoption within DoD – need to get to next plateau.</td>
<td>(H&amp;C)</td>
</tr>
<tr>
<td>Funding champion needed for R&amp;D to pilot adoption activities going forward from May 2011.</td>
<td>(H&amp;C)</td>
</tr>
<tr>
<td>Initiating a model based engineering approach will require investment in tools, training, and infrastructure. It must be institutionalized to be cost effective; the initial investment may be cost prohibitive if only used on one project.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Model based engineering approaches and tools must be integrated with enterprise-level processes.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Training in model based engineering is necessary, but not sufficient.</td>
<td>(Bergenthal)</td>
</tr>
<tr>
<td>Must address stove-piped responsibilities, requiring a strong interdisciplinary team to support concurrent engineering processes and practices.</td>
<td>(Bergenthal)</td>
</tr>
</tbody>
</table>
Network Centric Manufacturing (NCM) is defined as “a manufacturing supply chain management approach that integrates the smart design, rapid assembly and seamless coordination of dynamic supplier networks to accelerate production, reduce costs and mitigate risk. By coordinating both the business and manufacturing processes at each tier of the production supply chain, NCM helps manufacturers in today’s distributed environment regain the efficiencies of single-facility production.” 72 These supplier networks have three key traits:

- **Agility**: the ability to quickly change form and structure.
- **Connectivity**: the ability to coordinate and collaborate regardless of disparate computer systems.
- **Visibility**: the ability to see individual processes throughout the network. 73

The two organizations that are providing the most thought leadership and coordination for the Network Centric Manufacturing (NCM) community of interest are DSN Innovations 74 and the National Council for Advanced Manufacturing (NACFAM) 75. These organizations have co-sponsored the annual NCM Forum since 2007, and publish proceedings for these forums.

The NCM community recognizes that the “command and control” hierarchical supply chain management model alone will not work in an NCM environment. The complexity and distribution of risks within the supply network require some balanced use of self-regulating networks that are incentivized to operate within NCM behaviors. There is also an imperative to foster new kinds of collaboration and trust to enable NCM strategies. 76

New tools are required to apply the principles of NCM: 77

- Master scheduling tools.
- Visibility tools that give insight into the entire supply chain, including manufacturing processes, not just shipment.
- Communication and collaboration tools that facilitate collaboration around technical data and decrease the time and effort for chain-wide communications.
- Model based enterprise tools to create and reuse digital product definitions within the supply chain.

The 2009 NCM Forum emphasized the last point about reuse of product data, saying that, “The insufficient capture, reuse and maintenance of data over decades of program management creates a challenge for the NCM vision. The failure of organizations to retain and capture this

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72 DSN Innovations web site. See [http://www.dsninnovations.org/resources/about-ncm](http://www.dsninnovations.org/resources/about-ncm)
74 See web site at [http://www.dsninnovations.org/](http://www.dsninnovations.org/)
knowledge base results in the continual repetition of non-recurring engineering processes which ultimately multiply a product’s total life cycle costs.”

DSN Innovations describes a key benefit of NCM, which is resiliency of the supply chain. Resiliency is the ability of the manufacturing enterprise to return to its original state or move to a new more desirable state after being disturbed. DSN notes that NCM “addresses a critical paradox of static manufacturing supply chains – the rigidity that is intended to mitigate risk and support cost control can actually introduce greater risk by limiting the flexibility required to control costs in continually changing environments.”

DSN Innovations also describes the need for organizations throughout the supply chain to adopt a stronger culture of collaboration. Executives must drive the changes in both the formal and informal culture across the enterprise. The culture must encourage the sharing of mutually beneficial information more openly, development of agreements based on common outcomes, and incentives for effective collaboration. In a collaborative culture, buyers and sellers can strengthen the enterprise’s resiliency and open new conduits for product innovation, smarter design, faster problem resolution and greater competitive advantage.

Robert Rearden, VP of Supply Chain Integration, Lockheed Martin, describes how system integrators are best positioned to integrate the supplier networks. He also asserts that collaboration and trust lie at the heart of effective Net-Centric relationships. At the 2008 Network Centric Manufacturing Forum, Mr. Rearden described how Lockheed Martin is implementing NCM practices on the F-35 program.

Although DSN Innovations and NACFAM are facilitating discussions in the NCM community, NACFAM acknowledges that more empowered leadership is required to achieve the NCM vision. In 2009, Mr. Mittlestadt of NACFAM observed that,

> Although the development of tools, standards, and processes to support the NCM vision are underway, they are happening in an ad-hoc manner. The NCM Forum provided the opportunity to hear status reports on these activities (such as those at Lockheed Martin on the F-35 program and at Boeing on the 787 program), but no organization is bringing these pieces together in a way that ensures their compatibility, which could result in a loose assemblage of solutions that lack the transformative power and cost savings benefits of an integrated system. We believe that until an empowered organization takes the lead in establishing an NCM infrastructure, tools and standards may continue in development but

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miss opportunities for interoperability. Government and industry should take action on driving an infrastructure that supports NCM by facilitating the connections and transactions that enable the formation of efficient supplier networks that replace the rigid supply chains that we know today.  

Thought leaders in the NCM community of interest advocate both public and private investment in NCM capabilities. A 2007 white paper by Kessler, Mittlestadt, and Russell asserts the following.

We believe that these necessary elements of infrastructure also created by the fundamental power of market forces will still be insufficient to realize the preferred NCM future as swiftly as is technically possible and socially desirable. Thus some elements of the required infrastructure must be established through wise and sustained public investment. This investment will take many forms. We identify here ten objects of public investment that can support desirable development of network-centric manufacturing.

The paper lists investment areas such as basic science, development and deployment of enabling standards, best practices, and policy leadership and coordination.

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84 “Infrastructure in the Possible Futures of Network-Centric Manufacturing,” Kessler, Mittlestadt, and Russell, June 2007. Dr. William Kessler is from the Tennenbaum Institute, Georgia Tech. Mr. Mittlestadt was the CEO of NACFAM. Download at: http://www.nacfam.org/Portals/0/NACFAM%20Misc%20Files/NCMThoughtPaper.pdf
The table summarizes the targeted problems, solution strategies, benefits, and barriers to implementation for Network Centric Manufacturing. These are drawn from the following sources.

- DSN Innovations Web Site, (DSN About NCM)\(^85\)
- 2008 Network Centric Manufacturing Forum – White Paper, (NCM 2008)\(^86\)
- Christopher Peters, DSN Innovations, (Peters)\(^88\)
- Dennis Thompson, DSN Innovations, (Thompson)\(^89\)
- Bob Rearden, Lockheed Martin, (Rearden)\(^90\)

<table>
<thead>
<tr>
<th>Network Centric Manufacturing Community of Interest Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Targeted Problems</strong></td>
</tr>
<tr>
<td>Coordinating complex, geographically dispersed suppliers that use different software platforms, manufacturing processes, business processes—and even languages. (DSN About NCM)</td>
</tr>
<tr>
<td>The lack of common systems or synchronized scheduling undermines on-time delivery, quality, and ultimately, profitability. (DSN About NCM)</td>
</tr>
<tr>
<td>The disconnections across multiple supplier tiers can block the communication that enables innovation and cost control. (DSN About NCM)</td>
</tr>
<tr>
<td>The “manufacturing supply chain sinkhole,” which is the gap between full scale production and sustainment, where established resources drop off and new resources must be developed to climb out. (Thompson)</td>
</tr>
<tr>
<td>Manufacturing supply chain disruptions. (Peters)</td>
</tr>
<tr>
<td><strong>Solution Strategies</strong></td>
</tr>
<tr>
<td>Dynamic supplier networks based on common standards, technologies and business processes. (DSN About NCM)</td>
</tr>
<tr>
<td>Communicative networks that share information throughout the manufacturing supply chain, regardless of disparate systems. Communication improvements are enabled by software-neutral viewers, technical data exchange standards and tools that facilitate and archive collaboration. (DSN About NCM)</td>
</tr>
<tr>
<td>Coordinated networks that permit supply chain participants to share production schedules and progress throughout the chain. (DSN About NCM)</td>
</tr>
<tr>
<td>Coordination improvements that are enabled by technologies that provide visibility into the manufacturing processes of the extended supply chain and a common master schedule. (DSN About NCM)</td>
</tr>
<tr>
<td>Agile networks that can easily be reconfigured from order-to-order with minimal cost and effort. Agility improvements are enabled by the distribution of details about supply chain participants and their roles, common contract terms and outcome-oriented acquisition strategies. (DSN About NCM)</td>
</tr>
<tr>
<td>Advanced technical data packages (A-TDPs) that provide specific and proven manufacturing processes to be followed, reduce non-recurring engineering time, and shorten production ramp-up. (Peters)</td>
</tr>
</tbody>
</table>

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\(^{85}\) DSN Innovations web site. See [http://www.dsninnovations.org/resources/about-ncm](http://www.dsninnovations.org/resources/about-ncm)


### Network Centric Manufacturing Community of Interest Analysis

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Barriers to Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robust engineering change management tools that communicate changes immediately throughout the entire supply chain. (Peters)</td>
<td>Procurement practices that impede dynamic supplier networks with: unnecessary process steps for negotiating and executing contracts; supplier selection primarily based on price. (Peters)</td>
</tr>
<tr>
<td>Robust database of suppliers that includes multiple layers of capabilities (machines, processes, ability to collaborate, ability to innovate). (Peters)</td>
<td>Moving to a more collaborative operating culture between organizations, and a lack of leadership to move organizations towards greater collaboration. (Peters)</td>
</tr>
<tr>
<td>Sourcing tools that streamline the sourcing process, making it easier to solicit more suppliers with less effort while protecting intellectual property. (Peters)</td>
<td>New tools and skills and process capability frameworks are required. (Rearden)</td>
</tr>
<tr>
<td>Standards, such as ISO 10303, that facilitate the exchange and management of product manufacturing information. (Peters)</td>
<td>New behaviors are required to optimize the whole, not the parts. Communicating the Big Picture is challenging. The Difference between operational sovereignty and industrial sovereignty must be understood. More knowledge on how to establish and sustain intense collaborative relationships is needed. (Rearden)</td>
</tr>
<tr>
<td>Smart machine integration tools that improve the ability to produce a first part correctly without unscheduled delays. (Peters)</td>
<td>Governmental restrictions based on older models of low trust must be replaced with high trust systems based on high standards for quality, performance and ethics within the network. (NCM 2008)</td>
</tr>
<tr>
<td>“Available capacity” matchmaking that allows suppliers to anonymously post available capacity for given manufacturing processes. (Peters)</td>
<td>High complexity of managing a supply chain network with many suppliers, such as the 1,100 suppliers in the F-35 program. (NCM 2008)</td>
</tr>
<tr>
<td>Supplier risk assessment tools that monitor financial viability, and tracks potential risks such as natural disasters, labor disputes, geopolitical conflicts, etc. (Peters)</td>
<td>International Traffic in Arms Regulations (ITAR) that place complex restrictions on the flow of data and parts through the supply chain. (NCM 2008)</td>
</tr>
<tr>
<td>Tools to enhance interoperability between independent firms across the globe, extending to business practices and standards. Manufacturing Data Packages that are more compatible, so a broader range of manufacturing capabilities can be integrated into the supply network. (NCM 2008)</td>
<td>Diffused authority/responsibility, requiring new approaches to decision making and operational coordination. (NCM 2008)</td>
</tr>
<tr>
<td>Methods for governing the supply network. Govern a network in which both design and manufacturing are occurring simultaneously at different firms, change is happening in real time, and rapid response is vital to success. Methods for a “self-regulating network” that uses incentives, inhibitors and standards to reward collaboration, innovation and interoperability solutions. (NCM 2008)</td>
<td>Benefits</td>
</tr>
<tr>
<td>Modelling of NCM networks. (NCM 2008)</td>
<td>Dynamic supplier networks deliver value to every tier by allowing real-time responses to real-time demands. (DSN About NCM)</td>
</tr>
<tr>
<td></td>
<td>Communication networks allow all participants to gain access to accurate and timely information, along with the ability to collaborate around that information, reduce cycle times and avoid costly mistakes. (DSN About NCM)</td>
</tr>
<tr>
<td></td>
<td>Coordinated networks allow decision makers to know the status of work-in-progress, providing an early warning system—helping increase efficiencies for downstream suppliers and the customer. (DSN About NCM)</td>
</tr>
<tr>
<td></td>
<td>Agility helps minimize disruptions and maximize profits, whether responding to a change in market demand or the loss of a key supplier. (DSN About NCM)</td>
</tr>
<tr>
<td></td>
<td>Bridge the “manufacturing supply chain sinkhole” through better use of A-TDPs to maintain data and streamline setup of new suppliers of legacy parts. (Thompson)</td>
</tr>
<tr>
<td></td>
<td>Improved supply chain resilience – the ability to adapt and thrive in the face of disruption. (Peters)</td>
</tr>
<tr>
<td>Network Centric Manufacturing Community of Interest Analysis</td>
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<tr>
<td>-------------------------------------------------------------</td>
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</tr>
<tr>
<td>Incompatible, inconsistent, or non-existent interfaces (between design systems, MRP/ERP systems, logistics systems) which defeat information sharing, increase the time and cost of transport, and multiply uncertainties and risk. (NCM 2008)</td>
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</tr>
<tr>
<td>Requirement to invent the solutions to NCM implementation while doing NCM, especially while ramping up production. (NCM 2008)</td>
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<tr>
<td>Scale of investments required leading to increased financial exposure to NCM problems. (NCM 2008)</td>
<td></td>
</tr>
<tr>
<td>Strong market pull for NCM research and development does not yet exist. Incentives favor parochial solutions. A strong national champion of NCM has yet to emerge in industry. (NCM 2008)</td>
<td></td>
</tr>
<tr>
<td>Need to socialize the network. Information technology cannot substitute for human interaction and decision making. Human relationships are important to building trust, gauging risk, and forming collaborative partnerships. (NCM 2008)</td>
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</tbody>
</table>
3.9 Service Oriented Manufacturing

Service Oriented Manufacturing (SOM) is an area of interest that seeks to apply many of the methods of Service Oriented Architecture (a mature practice from the information technology industry) to the manufacturing industry. Jack White defines SOM this way:

- An architecture for exposing and accessing manufacturing processes and supporting services in a way that explicitly identifies the capability, the level of service, and cost while hiding the complexity of providing the service.
- Loose coupling, standard interfaces, common vocabulary.
- Conforms to the notions of network-centric manufacturing and model based enterprise.
- Better aligns industry incentives with the needs of DoD.
  - Services can be designed to explicitly provide improved visibility and risk management.
  - Allows for more balanced supply and demand.
- Not a closed set of “standard” service definitions.
- A set of architectural standards for composing service description using a standard ontology for manufacturing.
- Contains basic services for the management of services, such as: service publishing, discovery, composition, orchestration, and assurance.

McGrath and White say that while service oriented manufacturing is not new, “what is new here is the effort to make services a platform for innovation and greater market reach for U.S. manufacturing firms. SOM can help rationalize and deploy manufacturing services to reduce transaction costs, open up new markets, manage customer-supplier trust issues, and spur the rapid deployment of innovation across U.S. manufacturing sectors.”

McGrath and White further assert that, “We believe that SOM will be a platform for a host of new innovations in manufacturing. Services offer a way to decouple the introduction of new and innovative manufacturing concepts from the information and material management “plumbing” that often inhibits innovation. Specifically SOM can provide a new platform for net-centric services and better management of product, process, and coordination information. We believe that SOM is highly complementary to other initiatives that are addressing model based manufacturing and network-centric manufacturing.”

They continue: “A manufacturing service model will allow for the rapid introduction of services in several aspects of manufacturing:

- Product-Oriented Services, such as Product and Process R&D, Engineering and Design, Cost Estimation (based on service cost), Product Risk Management, Field Support, Sustainment, Technology Refresh

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92 “Service Oriented Manufacturing,” Mike McGrath (ANSER) and Jack White (Jacobs Technology), June 2010. Download at: https://activewiki.net/display/SOMPublic/SOM+White+Paper+Mcgrath-White
• Process-Oriented Services, such as Capability Management – features, tolerances, Production, Supply Chain Management, Supply Chain Visibility, Cost/Capability to Promise, Order Fulfillment, Exception and Event Management, Collaborative Planning and Forecasting
• Logistic Services, such as Vendor Managed Inventory; Configuration, Pre-Assembly, In-sequence Shipping, Distribution and Delivery, Return Management
• Discovery and Contracting, such as Standard Terms”

The table summarizes the targeted problems, solution strategies, benefits, and barriers to implementation for Smart Manufacturing. These are drawn from the following sources.

• “Service Oriented Manufacturing,” Mike McGrath and Jack White (M&W) 93
• “From Vertical to Virtual: The Case for Service Oriented Manufacturing,” Jack White (White) 94
• “Systems 2020 Strategic Initiative Final Technical Report,” Boehm & McGrath, pgs 24-27. (B&M) 95

<table>
<thead>
<tr>
<th>Service Oriented Manufacturing Community of Interest Analysis</th>
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<tbody>
<tr>
<td><strong>Targeted Problems</strong></td>
</tr>
<tr>
<td>People are needed to mediate manufacturing services today much more than in IT. Manual effort adds time, complexity, and transaction costs to the manufacturing process, but is necessary to work across “seams” between design and manufacturing, and among elements of the supply chain. (B&amp;M)</td>
</tr>
<tr>
<td>Human designers must mediate the complex interactions between functional design requirements, parts design and selection, and manufacturing processes. (B&amp;M)</td>
</tr>
<tr>
<td>Purchasing agents must discover what components and manufacturing services are available, and at what price, in a constantly changing market. (B&amp;M)</td>
</tr>
<tr>
<td>Human production planners must orchestrate a dynamic process to reserve the right resources and get the right sequence of manufacturing and assembly steps to come together at the right points in time and space. (B&amp;M)</td>
</tr>
<tr>
<td>Human quality control planners must ensure a service meets specifications and is delivered on time. (B&amp;M)</td>
</tr>
<tr>
<td>OEMs are concerned with identifying trusted suppliers and then more tightly managing those suppliers. (M&amp;W)</td>
</tr>
<tr>
<td>Suppliers are concerned with greater competition and the overhead cost associated with marketing and then working with new customers. (M&amp;W)</td>
</tr>
<tr>
<td>U.S. manufacturers are burdened with high costs to market their services outside of their traditional product sectors. (M&amp;W)</td>
</tr>
<tr>
<td>U.S. suppliers need a “break out” strategy for offering their capabilities in a more efficient and effective manner, reducing marketing costs, and reducing the transaction costs traditionally associated with doing business in supply chains. (M&amp;W)</td>
</tr>
<tr>
<td>OEMs need a way to find and engage new suppliers while addressing concerns over the pedigree of materials, counterfeit parts, and the risk associated with suppliers. (M&amp;W)</td>
</tr>
</tbody>
</table>

93 “Service Oriented Manufacturing,” Mike McGrath (ANSER) and Jack White (Jacobs Technology), June 2010. Download at: https://activewiki.net/display/SOMPublic/SOM+White+Paper+Mcgrath-White
**Service Oriented Manufacturing**  
**Community of Interest Analysis**

Despite advances in networking and information technology most manufacturing “enterprises” today manage “distributed manufacturing” in supply chains with centralized planning and execution systems. Extending centralized management to globalized production networks has exposed the fragility of these solutions. (M&W)

## Solution Strategies

<table>
<thead>
<tr>
<th>Strategy</th>
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<tbody>
<tr>
<td>Build a taxonomy of services around commodity segmentation strategy. (White)</td>
</tr>
<tr>
<td>Develop semantic structures for domain-specific, machine-interpretable product and process information that can drive manufacturing services without the need for human mediation of ambiguities. (B&amp;M, pg. 27)</td>
</tr>
<tr>
<td>Develop smart registries of services that can operate on this information, and mechanisms for discovery and coordination with information that is distributed across the manufacturing community. (B&amp;M, pg. 27)</td>
</tr>
<tr>
<td>Develop design rules, reasoning engines and resource allocation approaches that can match product and process needs with available services and constraints. (B&amp;M, pg. 27)</td>
</tr>
<tr>
<td>Develop dynamic scheduling tools and automated brokers that can orchestrate supply chain and dynamic production planning solutions faster and better than humans. (B&amp;M, pg. 27)</td>
</tr>
<tr>
<td>Develop open and scalable interface standards and service level agreements that extend SOA to handle manufacturing information, and wrappers to make legacy systems compliant with the interfaces. (B&amp;M, pg. 27)</td>
</tr>
<tr>
<td>Develop mechanisms to assure trusted services. (B&amp;M, pg. 27)</td>
</tr>
<tr>
<td>Build a set of use cases and a road map for SOM – This activity will involve building a road map that guides the rest of the effort to build and launch the SOM infrastructure and provide for meaningful pilots and test cases. The test cases will provide the context for early developments and a means for establishing benchmarks for measuring success. (M&amp;W)</td>
</tr>
<tr>
<td>Develop the SOM infrastructure – Establish the architecture, standards, and common vocabulary needed to support SOM. Work is needed on open and scalable interface standards and service level agreements that extend SOA to handle manufacturing information as well as wrappers to make legacy manufacturing-systems compliant with the interfaces. The SOM infrastructure will extend SOA concepts to manufacturing equipment and manufacturing processes. Communities of Interest will be formed to work on vocabularies and common process definitions. Explore ways to “lean out” regulatory and contractual issues for service and to expand on the inherent “performance-based” nature of services. (M&amp;W)</td>
</tr>
<tr>
<td>Imitate Grand Challenges, Proof of concept, and Pilots – The SOM initiative needs a set of public activities to showcase progress through the implementation of proofs of concept and pilots that test and demonstrate the efficacy of SOM-based solutions. (M&amp;W)</td>
</tr>
</tbody>
</table>

## Benefits

<table>
<thead>
<tr>
<th>Benefit</th>
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</thead>
<tbody>
<tr>
<td>For buyers: Expose and increase access to superior manufacturing capabilities on a service basis. (White)</td>
</tr>
<tr>
<td>For suppliers: Increase access to markets through standard interfaces for niche services and commodity services. (White)</td>
</tr>
<tr>
<td>Increase productivity, agility, and competitiveness through rapidly reconfigurable relationships. (White)</td>
</tr>
<tr>
<td>For DoD: Meet defense industrial base needs for assured sources of supply built on the best capabilities of proven service providers (both military and commercial). (White)</td>
</tr>
<tr>
<td>New opportunities for manufacturers to provide a richer set of value-add services (and diversity in their sources of revenue) in support of their products. (White)</td>
</tr>
<tr>
<td>Lower barriers to small and medium enterprises entering new markets. (White)</td>
</tr>
<tr>
<td>Improve the performance of suppliers and supply networks through collaboration, lower transaction costs, and enabling cross network planning, scheduling, and coordination. (White)</td>
</tr>
<tr>
<td>Improve supply security (risk, visibility, material assurance, trust). (White)</td>
</tr>
<tr>
<td>Simplify sourcing and contracting through new types of performance-based relationships. (White)</td>
</tr>
<tr>
<td>Making product and process data available as a service can shorten the time for sub-tier suppliers to respond to both initial orders and changes. (B&amp;M)</td>
</tr>
<tr>
<td>SOM will provide new ways of addressing interoperability and the rapid exchange of product, process, cost, and coordination information. (M&amp;W)</td>
</tr>
<tr>
<td>SOM will make quantifying supplier capabilities and the exact terms of service (expressed as service level agreements) easier, thus reducing risk associated with new suppliers. (M&amp;W)</td>
</tr>
<tr>
<td>SOM will simplify defining risk management and coordination services. (M&amp;W)</td>
</tr>
<tr>
<td>SOM will provide greater supply chain visibility and assurance to customers. (M&amp;W)</td>
</tr>
</tbody>
</table>
### Service Oriented Manufacturing

**Community of Interest Analysis**

**Barriers to Implementation**

The differences between IT and manufacturing make it challenging to apply SOA methods to SOM. Unlike IT, manufacturing is tied to closely coupled product-process interactions that are often product or industry specific. Manufacturing is constrained by physical capacity and physical movement of material and while IT services are generally offered as stateless services a manufacturing process always has states of material availability, tooling, and current capacity. Also, unlike IT, manufacturing is rarely governed by formal architectural specifications. (M&W)
3.10 Smart Manufacturing

Smart Manufacturing and Smart Process Manufacturing are communities of interest led by the Smart Process Manufacturing Engineering Virtual Organization Steering Committee. The committee is led by Jim Davis of UCLA and Tom Edgar of University of Texas at Austin, and its initial funding was provided by the National Science Foundation. The committee hosted a workshop for industry leaders and published its full report in November 2009.

Smart Process Manufacturing (SPM) is defined as, “an integrated, knowledge-enabled, model-rich enterprise in which all operating actions are determined and executed proactively applying the best possible information and a wide range of performance metrics.”

They define Smart Manufacturing (SM) in similar terms: “a dramatically intensified knowledge-enabled industrial enterprise in which all business and operating actions are executed to achieve substantially enhanced energy, sustainability, environmental, safety, and economic performance.”

SPM recognizes its dependence on cyber infrastructure, which NSF defines as, “the coordinated aggregation of software, hardware and other technologies as well as human expertise to support current and future discoveries and to integrate relevant and often disparate resources to provide a useful, usable, and enabling computational and data framework characterized by broad access.”

The scope of Smart Process Manufacturing is primarily, but not exclusively, at the facility level, putting much less emphasis on enterprise-level solutions. The community describes its scope this way:

*The full scope of Smart Process Manufacturing extends from requirements, product and process design to execution, delivery and life-cycle support. For our purposes, the major emphasis is on the processing environment, in which raw materials are converted to products via mechanical, chemical or biological processes. This includes both continuous and batch manufacturing, web/film/sheet processes as well as operations that produce intermediates that are essential to the manufacturing processes. In further defining the SPM environment we include planning, scheduling, optimization, monitoring, control and the ability to respond effectively to changing performance drivers. We are interested in the capability, tools and infrastructure that ensure that processes are seeking, at every instant in time, the optimum delivery of the best possible product without interruption, incident or cause for alarm. We are further interested in a high level of responsiveness to market shifts, customer demand, global economics and political and socioeconomic factors.*

Chapter 4 of the Operations and Technology Roadmap offers a relatively detailed roadmap of solutions and capabilities to be developed to realize the vision. At 25 pages in length, it is short.

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96 See the organization’s web site at [https://smart-process-manufacturing.ucla.edu/](https://smart-process-manufacturing.ucla.edu/)
enough to read easily, but too long and detailed to adequately summarize here. Those who are planning investments that are aligned with the Smart Process Manufacturing community of interest are strongly encouraged to review it.

The community includes the Smart Manufacturing Leadership Coalition (SMLC), which is described as a broad cross section of manufacturing practitioners across industry segments, technology suppliers, manufacturing consortia, government laboratories, and research universities. Notable among the 34 listed members are several large chemical companies (Dow, DuPont, Eastman, Eli Lilly, Merck, Owens Corning, Pfizer, Exxon Mobil, Shell), process control companies (Emerson, Honeywell, Rockwell Automation), as well as other large manufacturers: Alcoa, Ford, General Mills, and General Motors. The SMLC also includes U.S. Federal government representatives from OSTP, DOE, NIST, DOD, and NSF.

The SMLC actively promotes the formation of a Smart Manufacturing Public-Private Partnership Program. They describe the benefits of such a program this way:

A “Smart Manufacturing” public-private partnership program can revitalize America’s industrial sector by increasing global competitiveness and exports, providing sustainable jobs, and improving energy, environmental, health and safety performance. IT-enabled smart factories and supply networks can better respond to national interests and U.S. strategic imperatives. Smart manufacturing will be able to dramatically reduce production costs depending on industry segment. Wide-spread application of digital factory enterprise tools will improve time-to-commercialize new products at least tenfold (10x). Virtual factory operational models can cut model deployment costs by 80 percent, reduce safety incidents 25 percent, and improve energy efficiency by 25 percent and overall operating efficiency by at least 10 percent. IT-enhanced and standardized supply networks can deliver step-change reductions in inventories and customers’ response times for customized products and facilitate traceability throughout the supply chain.

The table summarizes the targeted problems, solution strategies, benefits, and barriers to implementation for Smart Manufacturing. These are drawn from the following sources.

- Smart Manufacturing Engineering Virtual Organization Steering Committee, (SPMEVOSC)\(^{103}\)
- “Smart, Safe, and Sustainable Manufacturing,” Bernaden (Bernaden)\(^{104}\)
- “Implementing 21st Century Smart Manufacturing,” Jim Davis, UCLA. (Davis)\(^{105}\)
- “Smart Manufacturing” Public-Private Partnership Program,” (SMP4)\(^{106}\)

| Smart Manufacturing  
<table>
<thead>
<tr>
<th>Community of Interest Analysis</th>
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</thead>
<tbody>
<tr>
<td><strong>Targeted Problems</strong></td>
</tr>
<tr>
<td>Manufacturing using lots of unskilled labor is no longer economically viable in the U.S; automation is essential. (Bernaden)</td>
</tr>
<tr>
<td>One-Off Models in Operations. (SPMEVOSC)</td>
</tr>
<tr>
<td>Dispersed intelligence that fails to support timely decisions. (SPMEVOSC)</td>
</tr>
<tr>
<td>Unintelligent systems that fail to take action to optimize performance. (SPMEVOSC)</td>
</tr>
<tr>
<td>Proprietary systems that fail to share critical information. (SPMEVOSC)</td>
</tr>
<tr>
<td>Unpredictable industry that disrupts efficient production. (SPMEVOSC)</td>
</tr>
<tr>
<td>Poor product quality. (SPMEVOSC)</td>
</tr>
<tr>
<td>High cost of plant operations. (SPMEVOSC)</td>
</tr>
<tr>
<td>Low effectiveness/efficiency of supply chain management. (SPMEVOSC)</td>
</tr>
<tr>
<td>Poor manufacturing process reliability. (SPMEVOSC)</td>
</tr>
<tr>
<td>Less than perfect environmental, health and safety performance. (SPMEVOSC)</td>
</tr>
<tr>
<td>Lack of infrastructure for facilitating innovation and problem solving by workers. (SPMEVOSC)</td>
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<table>
<thead>
<tr>
<th><strong>Solution Strategies</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>IT-enhanced and standardized supply networks. (SMP4)</td>
</tr>
<tr>
<td>Standardize and enhance industrial plant floor and supply chain data capture technologies. (SMP4)</td>
</tr>
<tr>
<td>Establish a clearinghouse, gateway, and technology transfer platform for community-sourced simulation and modeling tools. (SMP4)</td>
</tr>
<tr>
<td>Application of integrated monitoring and measurement. (SPMEVOSC)</td>
</tr>
<tr>
<td>Application of models and simulations, particularly as decision support tools. (SPMEVOSC)</td>
</tr>
<tr>
<td>Data interoperability to seamlessly exchange electronic product, process, and project data between collaborating groups and across design, construction, maintenance and business systems. (SPMEVOSC)</td>
</tr>
<tr>
<td>Networked sensors throughout the enterprise for data collection, data communications, automated control systems, long and short term planning, predictive modeling, optimization, environmental health &amp; safety management. Data fusion and information integration to create useful, accessible knowledge is essential in a network-centric manufacturing environment. (SPMEVOSC)</td>
</tr>
<tr>
<td>Models based on a physics-based understanding of material properties. (SPMEVOSC)</td>
</tr>
<tr>
<td>Multi-scale dynamic modeling and simulation and large scale optimization. (SPMEVOSC)</td>
</tr>
<tr>
<td>Scalable, requirements-based multi-level security. (SPMEVOSC)</td>
</tr>
</tbody>
</table>


\(^{104}\) “Smart, Safe, and Sustainable Manufacturing,” John A. Bernaden, Rockwell Automation, 20 April 2011.


### Smart Manufacturing
#### Community of Interest Analysis

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Details</th>
</tr>
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<tbody>
<tr>
<td>Improve time to commercialize new products by 10X.</td>
<td>(Davis)</td>
</tr>
<tr>
<td>Cut model deployment costs by 80%.</td>
<td>(Davis)</td>
</tr>
<tr>
<td>Reduce safety incidents by 25%.</td>
<td>(Davis)</td>
</tr>
<tr>
<td>Improve energy efficiency by 25%.</td>
<td>(Davis)</td>
</tr>
<tr>
<td>Improve overall operating efficiency by over 10%.</td>
<td>(Davis)</td>
</tr>
<tr>
<td>Increase global competitiveness of U.S. industry.</td>
<td>(Davis)</td>
</tr>
<tr>
<td>Create/preserve more highly skilled, sustainable U.S. jobs.</td>
<td>(Davis)</td>
</tr>
<tr>
<td>Improved traceability of products throughout the supply chain.</td>
<td>(Davis)</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Barriers to Implementation</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need for highly collaborative efforts throughout the enterprise, not just single-point solutions. Challenge is too large and complex for any single organization to solve alone.</td>
<td>(SPMEVOSC)</td>
</tr>
</tbody>
</table>
3.11 Standards for Interoperability

Many of the other communities of interest recognize the importance of making the many software tools involved interoperable. While they need not be integrated into a single package (such as Microsoft Office does with Word, Excel, and Powerpoint), they do need open and standardized interfaces for exchanging data (such as between web sites and web browsers, or between different e-mail programs). For any two software packages that ought to exchange data without errors, omissions, or distortions, there ought to be standards for what data is to be exchanged, and additional standards for the data exchange interfaces. In other words, “what do you exchange,” and “how do you exchange it?” These are the questions that bring together the many sub-communities that are grouped together here under the heading of “Standards for Interoperability.”

IMTI presents a very good discussion on standards and interoperability. IMTI asserts that “the shift to a global enterprise and supply network presents many new challenges. The communication of technical and business information through the supply chain primarily relies on a paper and electronic paper trail. The lack of interoperability of these systems costs literally billions of dollars each year and is the primary barrier to adaptability and growth for U.S. manufacturers.”

As evidence, IMTI offers three of the studies used in Chapter 2 of this report to quantify the potential cost avoidance of AME practices.

IMTI goes on to say: “Integration of modeling and simulation across conceptualization, design, and into production is expensive and not yet the state of practice. The lack of application of the manufacturing operations standards has made integration a barrier to realizing adaptive processes and interoperability. Further, it is difficult (from cultural, business process, and technical perspectives) to modify product and process workflows to take full advantage of these systems. Interoperability issues limit applications…. The lack of standards to support the transition from CAD data to programs and work plans that support manufacturing processes limits their adaptability, effectiveness, and efficiency. U.S. competitiveness is directly impacted by the lack of standardization and protection of proprietary protocols, which encourages large barriers created by single-vendor solutions.”

IMTI discusses several barriers preventing any authority from mandating the use of tools that are standards-compliant, non-proprietary, and open source:

- In most areas, there is no agreement on the structure of the knowledge and information in the field, and so no agreement exists on what entities or components must be interfaced, or how.
- Open standards do exist, but sometimes overlap or conflict with other standards.

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108 IMTI, page 7.
• Open standards must be unambiguous, sufficiently functional, and implemented by a critical mass of users. Today’s application suites are usually vendor platform-specific, using only that vendor’s applications and infrastructure.
• Conformance tests for standards must be better defined and used by all implementers. The newly formed Industrial Interoperability Compliance Institute (IIICI) has the mission to develop a certification process for a comprehensive set of criteria and certification levels to a given set of industrial systems standards.
• Up-front investment is required of users and vendors, and return on investment usually comes slowly.
• Users must drive the process, since vendors are not the primary beneficiaries of interoperability. However, some users have been disappointed by past standards efforts that did not deliver the promised results, and so they are reluctant to support further efforts. Participation in standards efforts is also hindered by downsizing and outsourcing trends.
• Vendors sometimes feel that by participating in a standards effort, they risk giving away the competitive advantage that has allowed them to become successful in the marketplace.

There are several communities of interest that are grouped together here under the heading of “Standards for Interoperability.” Each community is centered on a particular set of standards, and the fundamental goal of each set of standards is to improve communications and interoperability between all organizations and tools that would adopt the standards. This section provides a brief sampling of several standards communities that are relevant to AME, but this sampling is not intended to be a comprehensive list of relevant standards.
Aerospace Industries Association Electronic Enterprise Integration Committee (AIA EEIC)

The Aerospace Industries Association (AIA) has created a community of interest that is working to adopt or develop a wide range of relevant eBusiness standards.\(^{110}\) The AIA vision for eBusiness across the industry is that:

*All participants in the aerospace value chain will be able to exchange information relative to product design, business relationships, transactions, and product support across an information backbone which is open and accessible to all.*

This vision is being achieved through industry agreements on policy, infrastructure and standards, eliminating the need to force the adoption of common IT tools across the industry. AIA provides recommended (not mandatory) solutions to interoperability issues for supply networks. The recommendations are maintained by the Electronic Enterprise Integration Committee (EEIC).\(^ {111}\) The EEIC has developed a consistent methodology and framework for managing the business scenarios and solution components, with processes for developing recommended solutions and adopting new solution components. The methodology and framework are described in detail in the AIA eBusiness Implementation Guidebook.\(^ {112}\)

The AIA published the “Aerospace Industry Guidelines for Implementing Interoperability Standards for Engineering Data” in February 2009.\(^ {113}\) According to the AIA web site, these guidelines provide strategic and tactical guidance for the adoption by industry of a common standard-based information backbone for engineering data, using the ISO 10303-239 (PLCS) standard. This will enable interoperability for product definition data across the aerospace industry supply network and throughout the product life cycle, from design and production to consumption and operation, reducing the cost, risk and complexity and increasing the speed of working with suppliers and partners at any level.

The AIA uses four strategies for addressing the needs for various standards.\(^ {114}\) In decreasing order of preference, the strategies include:

- Adopt existing standard.
- Monitor external development - where the development is intended to deliver a necessary component.
- Participate in external development - where the work needs to be steered to meet AIA needs.
- AIA development - where no appropriate external tasks can be leveraged to meet our needs.

\(^{110}\) AIA web site at: [http://www.aia-aerospace.org/resource_center/ebusiness/#components](http://www.aia-aerospace.org/resource_center/ebusiness/#components)

\(^{111}\) A briefing describing the EEIC is at: [http://www.aia-aerospace.org/assets/ebusiness/EEIC%20101%20v1.6.ppt](http://www.aia-aerospace.org/assets/ebusiness/EEIC%20101%20v1.6.ppt)

\(^{112}\) Download the Guidebook at: [http://www.aia-aerospace.org/assets/ebusiness/Guidebook.doc](http://www.aia-aerospace.org/assets/ebusiness/Guidebook.doc)


\(^{114}\) From AIA web site at: [http://www.aia-aerospace.org/resource_center/ebusiness/#components](http://www.aia-aerospace.org/resource_center/ebusiness/#components)
The following standards and initiatives have been adopted, or are under consideration. Links to each are available on the AIA web site.¹¹⁵

- **Electronic Knowledge Management (EKM)**
- **Architecture standards**
  - Service Oriented Architecture (SOA) - adopted
  - Universal Data Element Framework (UDEF) - adopted
- **eAgreements**
  - Model Template Global Trading Partner Agreement (GTPA) - adopted
  - Global Electronic Collaborative Agreement (GECA) - adopted
  - Clickable GTPA - candidate
- **IUID/RFID**
  - Guideline for IUID Data Exchange Between Partner and Prime - adopted
  - Guideline for RFID Data Exchange (RFID) - adopted
- **Business transactions**
  - EDI Implementation Conventions and Business Examples - adopted
- **Product data**
  - Product Life Cycle Support (PLCS) - adopted
  - Standard for the Exchange of Product model data (STEP) - candidate
  - EIA-927 – candidate
  - ASD Spec S1000D for Technical Publications - candidate

### International Standard for the Integration of Enterprise and Control Systems (ISA-95)

According to the web site www.ISA-95.com, ISA-95 is the international standard for the integration of enterprise and control systems.¹¹⁶ ISA-95 consists of models and terminology. These can be used to determine which information has to be exchanged between systems for sales, finance and logistics and systems for production, maintenance and quality. This information is structured in UML models, which are the basis for the development of standard interfaces between enterprise resource planning (ERP) and manufacturing enterprise systems (MES, also called manufacturing execution systems). The ISA-95 standard can be used for several purposes, such as a guide for the definition of user requirements, for the selection of MES suppliers, and as a basis for the development of MES systems and databases.

The models and terminology of ISA-95 can be used for different goals. Some examples include:

- Use the hierarchical models to define how your company is structured when discussing departments and automation systems;
- Use the functional model to determine which departments and systems are responsible for the functions of interest;
- Use the functional model to determine which information flows from one department to another department, and which information flows from one automation system to another automation system;

¹¹⁵ From AIA web site at: [http://www.aia-aerospace.org/resource_center/ebusiness/#components](http://www.aia-aerospace.org/resource_center/ebusiness/#components)

• Use the definition of functions and information flows as a checklist, making sure that nothing is forgotten;
• Use the definition of functions and information flows as a dictionary, making sure that everybody is talking about the same thing;
• Use the object models to understand the relationship between different sorts of information;
• Use the object models and the attributes to exchange information;
• Use the object models and attributes as a basis for a database;
• Use the activity models for the specification of User Requirements;
• Use the activity models for vendor / solution selections; and so on.

The ISAE95 standard is developed with the objective to reduce the cost, risk, and errors associated with implementing interfaces between enterprise and production control systems. ISAE95 claims to offer the following benefits:

• Reduce cost: ISAE-95 can be used as a method to define the interface between enterprise and production control systems. By applying ISAE-95, costs can be reduced. You will know where to begin and how to continue. The integration of solutions from different suppliers will get less complex when all use this standard method.
• Reduce risk and avoid errors: ISAE-95 was developed by a group of companies like Honeywell, Sequencia, Foxboro, Yokogawa, Fisher Rosemount, Chevron, Dow Chemical, and SAP. They have combined their best practices into a consistent set of models and terminology: the ISAE-95 standard. They know how to make integration a success and, more important, how to avoid failures. You can use these best practices by applying the standard.
• Improve communication: Every manufacturing company uses its own terminology for describing functions, activities and departments within the enterprise. When you have to work with external consultants, like suppliers of process control software, or system integrators, communication will be difficult. The external specialist will have to deal with this problem every time they start a new project, or every time they are talking with different clients. So when you discuss interfaces, it’s a good idea to base this discussion on standard terminology.

117 From ISA-95 web site: http://www.isa-95.com/subpages/advantages/advantages.php
MIL-STD-31000 for Technical Data Packages

The scope of MIL-STD-31000 is to prescribe the requirements for preparing a technical data package (TDP), which is composed of one or more TDP elements and related TDP data management products. Selection of TDP levels, types, elements and TDP data management products to make up a TDP are based on the technical data needed to support acquisition and life cycle support strategies. A technical data package is defined as:

A technical description of an item adequate for supporting an acquisition strategy, production, and engineering and logistics support. The description defines the required design configuration or performance requirements, and procedures required to ensure adequacy of item performance. It consists of applicable technical data such as models, drawings, associated lists, specifications, standards, patterns, performance requirements, quality assurance provisions, software documentation and packaging details.

MIL-STD-31000 defines what elements make up a TDP; but, relies on other standards to define content and format. The standard references both ASME 14.41 to define the content of the model, and ISO 10303 was added for data exchange. Recent activity has focused on updating MIL-STD-31000 for three dimensional (3D) TDPs.

Standard for the Exchange of Product Model Data (STEP ISO 10303)

According to the AIA web site, STEP provides a comprehensive set of internationally-agreed integrated information models to address the problem of exchanging product information between dissimilar computer applications throughout the lifecycle of the product. Deployment of the STEP standard enables companies to have a proven single definition for all the product-related information related to individual products throughout their lifecycle, independent of changes in process and information technology. The standard enables suppliers to deliver and receive support information in a consistent form, irrespective of the source. Interoperability is facilitated by the adoption of common subsets of the standard, known as Application Protocols, to support particular information flows. PDES Inc. is the U.S.-led consortium for promoting STEP deployment.

The use of a standard to communicate product information between dissimilar systems avoids the cost of maintaining multiple translation services to support the supply chain. The STEP standard has been successfully deployed in the U.S. and elsewhere since 1996, in projects such as the C-17, Eurofighter Typhoon, Lockheed Martin PORT capability, Rockwell Collins and Raytheon products, Airbus A380, and interfaces between engine manufacturers and primes. It is also being used as the basis of the U.S./European LOTAR (Long Term Archiving and Retention) activities on Long-Term Data Retention.

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119 From AIA web site at: http://www.aia-aerospace.org/assets/ebusiness/step.doc
120 See the PDES Inc. web site at: http://pdesinc.aticorp.org/
From the customer viewpoint, ISO 10303 is recognized as the preferred method of product data exchange by the U.S. Navy, and its use is being actively promoted by USD (AT&L) for triservice application. DoD is also seeking to mandate STEP as the standard for delivery of product information through the DLA SPOE and other gateways such as WAWF, and the UID Office and U.S. Army components are encouraging industry to use STEP as a replacement for national standards such as EIA-836. It is recognized as the preferred standard for delivery of product information to the UK MOD.

The table summarizes the targeted problems, solution strategies, benefits, and barriers to implementation for Standards for Interoperability. The primary source of information in the table is from the Aerospace Industries Association Electronic Enterprise Integration Committee. (AIA EEIC). Other sources are cited in the footnotes.

<table>
<thead>
<tr>
<th>Standards for Interoperability Community of Interest Analysis</th>
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<tbody>
<tr>
<td><strong>Targeted Problems</strong></td>
</tr>
<tr>
<td>Multiple point-to-point data exchange solutions generate excessive cost and complexity. (AIA EEIC)</td>
</tr>
<tr>
<td>Lack of shared trust infrastructure impeding collaboration between partners. (AIA EEIC)</td>
</tr>
<tr>
<td>Increasing number of customer-unique portals adding cost to suppliers. (AIA EEIC)</td>
</tr>
<tr>
<td>Multiple, redundant, incompatible IDE systems within the industry. (AIA EEIC)</td>
</tr>
<tr>
<td>Incompatibilities in information exchange contribute to delay, rework, and error. (AIA EEIC)</td>
</tr>
<tr>
<td>Excessive cost and complexity impeding supply chain agility. (AIA EEIC)</td>
</tr>
<tr>
<td>Expected business results not yet realized with development of ebusiness standards. (AIA EEIC)</td>
</tr>
<tr>
<td>Need enabling capability to avoid one-off solutions and achieve transformational change. (AIA EEIC)</td>
</tr>
<tr>
<td><strong>Solution Strategies</strong></td>
</tr>
<tr>
<td>Orchestrate a common plan at industry level. Identify common ebusiness interface scenario models. Identify a consistent methodology for work. Normalize the data models and other components. Consistently connect electronic enterprise components to Enterprise Interface Solutions. (AIA EEIC)</td>
</tr>
<tr>
<td>Provide a forum for driving all electronic enterprise standards. An industry level response is needed to realize the benefits. (AIA EEIC)</td>
</tr>
<tr>
<td>Organize an “information backbone” composed of information standards (XML, EDI, UML, STEP, PLCS, S1000D), Internet standards (HTTP, HTML, FTP, SMTP), Public/Private Registries (UDDI, DoD XML Registry), Information security (SAML, PKI, TSCP), Web services (UDDI, WSDL, XML, SOAP), and standards bodies (OASIS, UN/CEFACT, ISO, W3C, E3AG) (AIA EEIC)</td>
</tr>
<tr>
<td>Information backbone built from policy, infrastructure, and standards; not common tools. (AIA EEIC)</td>
</tr>
<tr>
<td>AIA members will adopt existing standards; influence standards organizations through participation to meet member requirements; develop AIA standards when no applicable standard exists. (AIA EEIC)</td>
</tr>
<tr>
<td><strong>Benefits</strong></td>
</tr>
<tr>
<td>• Supplier benefits: reduced cost of order entry and administration; larger incentive for non-electronic suppliers to adopt ebusiness; avoid or minimize added staff to manage ebusiness orders; common interface to primes (customers).</td>
</tr>
<tr>
<td>• Prime (customer) benefits: Increased number of suppliers willing to accept ebusiness; implement new electronic processes to a more capable supplier base; reduce costs through simplification of processes and systems with adoption of standards; achieve a larger portion of ebusiness cost benefits; common adoption of eCollaboration capabilities and processes. (AIA EEIC)</td>
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Standards for Interoperability
Community of Interest Analysis

Benefits of STEP implementation include:

- Providing a single interface from a supplier to all their customers, reducing the cost of creating and maintaining multiple processes and tools.
- International standard facilitates collaboration with international partners and sales to international customers.
- Ensuring that the product information flow is independent from the different software tools used to support the business processes, allowing organizations to select and update their systems without disrupting the complete network of services.
- Enabling information on a product to be maintained in a usable form over its full life cycle, which is often measured in decades, far longer than the software tools, operating systems and equipment used to create the information in the first place.
- Use of a single integrated model to support different business functions with consistent information, avoiding the cost of synchronizing different information sources.
- Enforcement of information quality rules, avoiding costs arising from decisions made on inaccurate data.
- Translation to a standard form has additionally demonstrated significant improvements in information quality and cost reductions through early elimination of inconsistencies and errors.

Reduce cost, risk, and errors due to improved communication between partners. (ISA-95)

Barriers to Implementation

STEP is widely, but not universally, adopted. The quoted sources did not describe barriers to implementation.

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123 From ISA-95 web site at: http://www.isa-95.com/subpages/advantages/advantages.php
3.12 Systems 2020 and Engineered Resilient Systems

The Systems Engineering Research Center observes the following flaw in current defense acquisition systems:

*Traditional DoD system acquisition and development is a linear, sequential, requirements-first process over an extended number of years.... However, current acquisition and development support tools (contracting mechanisms, sequential process models, phase-specific support tools, complete-requirements-first review standards) make it difficult for DoD projects to realize the benefits of concurrent engineering.... The length of the process means that committed-to technologies are often stretched to meet distant future performance goals, typically with belated recognition of risks in technology readiness and manufacturing readiness. The linearity of the process involves many handoffs across organizational boundaries, leading inevitably to re-creation of data, miscommunication, errors, and late consideration of production potential and life cycle attributes. Design decisions based on aging concepts of operation and technical assumptions may not remain valid years later. The result is that systems entering production too often encounter problems of low manufacturing yield, high cost, and multiple design changes – and the problems increase as system complexity increases. The opportunity to achieve first pass success – that is, to deliver a system that meets the operational need without scrap, rework and extensive design changes in production – requires shortening the initial development content and timeline; eliminating or mediating the seams in the process; and, as much as possible, deferring change traffic to later evolutionary increments of capability.*

To address this issue, the Office of the Director, Defense Research and Engineering (DDR&E) of the Department of Defense has started a strategic initiative called “Systems 2020” to fundamentally change the capabilities of DoD and its commercial suppliers. Systems 2020 will allow suppliers to rapidly envision, conceptualize, design, and manufacture adaptable, cost effective defense systems that embody levels of reliability and trustworthiness commensurate with their intended missions and costs. A Request For Information (RFI) published on 3 January 2011 described the program in the following way.

“Recent conflicts have highlighted the need for the Department of Defense to be able to field capabilities and systems to respond rapidly to changing—and, often, previously unanticipated—threats. The Department is exploring various approaches as alternatives to the typical practice of fielding systems based on requirements that were defined years before the system’s initial use. Current requirements based systems tend to lead to “point solutions” designed to address specific threats, which in turn are assumed to evolve...

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slowly in time. With the pace of events and increasing agility of adversaries, systems of the future need to be far more flexible and adaptable to changing environments, without time consuming redesign or unacceptably burdensome hardware/software replacements. Systems need to be modifiable, reconfigurable or upgradable by reference to virtual models, by plug-replacing subcomponents, installing new “apps,” or upgrading hardware subsystems. Furthermore, the processes, components and products must facilitate ongoing assessment of their trustworthiness and reliability.”

“They should assist in managing and mitigating trust and reliability risks as systems are modified over time, and as they interoperate with other systems in a systems-of-systems environment. Systems 2020 is an initiative to perform research to develop and demonstrate engineering tools, technologies, and methods that facilitate the rapid conceptualization, design and manufacture of highly resilient, adaptable systems. These tools and techniques should enhance assurance of reliability and trustworthiness of systems, as an integral part of the process of helping designers explore trade spaces that include assessments of cost, quality and functionality. This initiative is focused on a specific design methodology called platform-based engineering, and the enabling tools and practices intended to foster platform-based engineering, which are identified as model-based engineering. Platform-based engineering and model-based engineering could make a significant contribution to rapid design and development of adaptable systems. These terms are defined below.

- **Platform-based Engineering (PBE)** is a design and development methodology that uses components and subsystems as building blocks in an enduring architectural framework to achieve desired functionalities across a broad range of product lines. The architectural framework provides a common core set of features, and the modular design allows for very rapid adaptation of a system to enable new capabilities and features. Further, subsystems should have utility across a number of product lines.

- **Model-Based Engineering (MBE)** employs a model-based (vs. paper-based) approach to system conceptualization, design and production, capturing design choices and details. MBE enhances design reuse, facilitates exploration of alternative design configurations and analysis of trade spaces. It increases productivity for implementing design changes. Ideally, MBE allows one to integrate the design of electronics, software, physical structure, mechanical systems, connectors, cabling, hydraulics, and all significant components into a virtual realization of a complex system.”

In early 2011, DDR&E began briefing a science & technology priority called “Engineered Resilient Systems (ERS).”[^126] In a June 2011 briefing, Dr. Neches described how Systems 2020 fits under the umbrella of ERS, alongside several other unnamed programs that will participate in

achieving the ERS vision. The briefing describes the distinctions between Engineered Resilient Systems and Systems 2020 in the following way.

- Engineered Resilient Systems:
  - A science and technology priority
  - Spans over 50 OSD, DARPA, Air Force, Army, and Naval Programs
  - Ten year span
  - Budget is all – and only – the sum of the program budgets
  - Coordination makes it more than the sum of its parts

- Systems 2020:
  - A specific program
  - One of a number participating in ERS
  - Five year span: GFY12 - GFY16
  - Has its own budget
  - You can bid on it

This AME Strategic Baseline report only covers the Systems 2020 perspective, and not ERS. At the time of this report’s final preparation stage, there was not enough detailed documentation of ERS available to warrant including ERS in the analysis and findings. ERS is a significant DDR&E undertaking with implications for AME, and so AME leaders are advised to seek periodic updates regarding ERS and engage with its leaders so that efforts can be coordinated as appropriate.

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The table summarizes the targeted problems, solution strategies, benefits, and barriers to implementation for Systems 2020. These are drawn from the following sources.

- DDR&E – June 2010 (DDRE Jun),\(^\text{128}\)
- DDR&E – October 2010 (DDRE Oct),\(^\text{129}\)
- Booz Allen Hamilton (BAH),\(^\text{130}\)
- Systems Engineering Research Center (SERC).\(^\text{131}\)

<table>
<thead>
<tr>
<th>Systems 2020 Community of Interest Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Targeted Problems</strong></td>
</tr>
<tr>
<td>Development takes too long. (DDRE Jun)</td>
</tr>
<tr>
<td>Change takes too long. (DDRE Jun)</td>
</tr>
<tr>
<td>Replacement takes too long. (DDRE Jun)</td>
</tr>
<tr>
<td>The environment is highly uncertain and complex. (DDRE Jun)</td>
</tr>
<tr>
<td>System complexity is growing. (DDRE Jun)</td>
</tr>
<tr>
<td>Need to move from “black box” to “glass box” for many systems and subsystems. (DDRE Jun)</td>
</tr>
<tr>
<td>Need to have far greater fungability of product lines across sensor/weapons systems. (DDRE Jun)</td>
</tr>
<tr>
<td>Need to improve our ability to predict complex system behavior across performance envelope. (DDRE Jun)</td>
</tr>
<tr>
<td>Need mechanisms to ensure post fielding flexibility to address unanticipated needs. (DDRE Jun)</td>
</tr>
<tr>
<td>Adversaries can use commercial technologies and new tactics to rapidly alter the threat to US forces. Unfortunately, DoD engineering and business processes are not structured for adaptability to meet these changing threats. New research, tools, and pilot efforts are needed to determine the best methods for building adaptable defense systems. (DDRE Oct)</td>
</tr>
<tr>
<td>Need to design trusted systems using components or subsystems of unknown or suspect trustworthiness, such as commercial technologies from around the globe. (DDRE Oct)</td>
</tr>
<tr>
<td>Virtual design modeling tools that work across domains, linking multiple systems or holistically modeling single systems, from cradle to grave, is limited. (BAH)</td>
</tr>
<tr>
<td>Model-driven manufacturing lacks capability in 1) multi-scale process modeling and 2) standards, including ontologies, for product and process model interoperability and reuse. (BAH)</td>
</tr>
<tr>
<td>Platform-based engineering: DoD does not develop product line architectures (PLA) effectively. (BAH)</td>
</tr>
<tr>
<td>The weakest link in systems engineering is often the link between what the warfighters need and what the development team thinks they need, together with a shared understanding of the operational environment and associated constraints and dependencies. (SERC)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Solution Strategies</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Model based engineering - Modeling and simulation tools for concurrent design, development, and manufacture. (DDRE Jun)</td>
</tr>
<tr>
<td>Applying product, process, property, environment, mission models to ensure rapid, concurrent, integrated development of adaptable systems. (DDRE Oct)</td>
</tr>
</tbody>
</table>


| Systems 2020 |
| Community of Interest Analysis |

Platform based engineering - Architectural and automated design tools to rapidly insert new capabilities. (DDRE Jun)

Applying architectural and automated design tools to develop a system structure/platform based on commonality, as well as planned variability. (DDRE Oct)

Platforms are reusable, reconfigurable, and extensible. (BAH)

Capability on demand - Systems embedded with organic adaption capabilities. (DDRE Jun)

Trusted systems design - Design methods and tools for system assurance that detect malice or enable self awareness. (DDRE Jun)


Virtual Environment for Concept Engineering: Collaboratively, interactively create models of desired system behavior. Develop better tools for concept development & evaluation, tools for concept validation throughout development, and trade analysis for upgrade options. (DDRE Oct)

Use Platform Based Engineering tools to design the system to address trust. Isolate suspect components, make them not part of the enduring core. Research the following:
- architectures to make systems less transparent to the attacker;
- methods, models for implementing trusted system design throughout system lifecycle;
- trustworthy assessment tools and methodologies (DDRE Oct)

Develop modeling environments for rapid evaluation of alternative concepts. In particular, models that allow designers to identify unanticipated couplings between domains. (BAH)

Develop modeling vehicles to validate the concept throughout the development lifecycle. (BAH)

Develop modeling vehicles to perform trade analysis for upgrade options in subsequent versions of products. (BAH)

Implement Platform based engineering through Product Line Architectures (PLAs), which are open architectures that have published, accepted interfaces to components that can be provided by different vendors. (BAH)

Develop tools and processes that can provide an efficient and interactive environment so that multiple stakeholders can create a shared mental model during the brainstorming process through the development of a concept of operations model which can be used throughout the lifecycle.
- More effective cognitive concept development environment.
- Environment for rapid evaluation of alternative concepts.
- Vehicle to validate the concept throughout the development lifecycle.
- Vehicle to perform trade analysis for upgrade options.
- Scalable capabilities for complex systems of systems. (SERC)

Develop an open systems engineering environment that allows the system to be built before it is built physically, with full community participation and early consideration of downstream issues. (SERC)

**Benefits**

Develop faster: Reduce by 3x the time to acquisition of first article for systems and solutions. (DDRE Jun)

Flexibility: Reduce by 4x the time to implement planned and foreseen changes in systems. (DDRE Jun)

Adaptable: Embed within systems the ability for changes at the tactical edge, as the mission evolves in unplanned and unforeseen ways, such as the IED threat. (DDRE Jun)

MBE will enable real time assessment of system changes, robust evaluation of different approaches. (DDRE Jun)

PBE will enable rapid changes to extensible product families to meet changing user environments and missions. (DDRE Jun)

PBE will reduce costs/schedules, increased quality & productivity, reduced logistics tail, increased competition, simpler training. (DDRE Oct)

Capability on demand will allow fielded systems to rapidly respond to a changing environment as the mission evolves in unplanned, unforeseen ways. (DDRE Oct)

Trusted Systems Design will allow us to take advantage of innovation in the global supply chain, while ensuring that our systems operate as intended. Composing assured systems from COTS will allow speedy adoption of COTS for the war-fighter. (DDRE Jun)
Accelerated time to fielding through ability to rapidly evaluate alternative concepts, improved communication with all stakeholders, and avoidance of lengthy redesign cycles. (BAH)

Increased quality through improved ability to support continuous system verification and validation throughout the life cycle, and ability to train deployment, service, and support personnel earlier in the life cycle. (BAH)

Increased flexibility through ability to rapidly evaluate changing threats and explore the solution space, and develop CONOPs to re-purpose existing/modified systems. (BAH)

Benefits of product line architectures (PLA) for Platform-Based-Engineering (PBE) include the following:
- Reduced time to deployment.
- Reduced cost
- Increased productivity
- Superior quality
- Simplified training
- Reduced logistics tail – less spares needed
- Increased competition
- Better leverage of human capital (free to focus on higher value tasks)
- Agility and flexibility (BAH)

Barriers to Implementation

It is challenging to meet System 2020 objectives while also maintaining or enhancing:
- Trust and Assurance – able to withstand exploitation before or after fielding, enabling the leveraging of global supply chains.
- Reliability – across a range of changing operational conditions.
- Interoperability – working with other systems to meet user needs. (DDRE Jun)

Developing cross-domain modeling tools is challenging for the following reasons: tool suppliers must be gotten on board; new tools providers must be encouraged; and there must be buy-in from industry and model based engineering trade and standard organizations.

Risk of insufficient DDR&E-external stakeholder buy-in. (SERC)
Risk of either prematurely or belatedly adopting desired technologies. (SERC)
Risk of failing to identify and address emerging DoD needs and opportunities. (SERC)
Risk of mismatches between matured, high-payoff Systems 2020 technologies and acquisition-practice disincentives towards their adoption. (SERC)
Chapter 4. Community of Interest Solution Strategies Organized to Support Consolidated Solution Strategy Recommendations

In reviewing the source literature for this report, over 100 solution strategies were identified and extracted from the literature. Those solution strategies were then grouped into categories and consolidated into seven top-level solution strategies.

If the seven solution strategies here are mapped to the three strategies in the AME definition offered in Chapter 1, the two lists of strategies do not sort out into neat, hierarchical groupings. Instead, the mapping shows that the two lists of strategies cross-cut each other to a large degree. This makes sense because the two lists serve different purposes. The AME definition’s list of three strategies is intended to be more long-term and visionary in nature, using language suitable for describing AME to people who are being introduced to AME for the first time. The seven strategies here are intended to be more near-term (1-5 years) in their perspective, and are suitable for describing technical and policy initiatives to be undertaken by AME leaders within that time frame.

The tables on the following pages show how Community of Interest (CoI) solution strategies were grouped together. The reader may use the Source CoI code to trace back to the community of interest that offered the solution, and then trace back to the original source document to review the original solution strategy in its original context. Presented this way, readers are empowered to better understand the original intentions at the source of each solution strategy.

The abbreviations (codes) for each source community of interest are given in the table below.

<table>
<thead>
<tr>
<th>Source CoI Code</th>
<th>Community of Interest</th>
<th>Source CoI Code</th>
<th>Community of Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVM</td>
<td>DARPA Adaptive Vehicle Make</td>
<td>NCM</td>
<td>Network Centric Manufacturing</td>
</tr>
<tr>
<td>OM</td>
<td>DARPA Open Manufacturing</td>
<td>SM</td>
<td>Smart Manufacturing</td>
</tr>
<tr>
<td>FoF</td>
<td>Factories of the Future Public-Private Partnership</td>
<td>SOM</td>
<td>Service Oriented Manufacturing</td>
</tr>
<tr>
<td>IM</td>
<td>Intelligent Manufacturing</td>
<td>SFI</td>
<td>Standards for Interoperability</td>
</tr>
<tr>
<td>MEMS</td>
<td>Manufacturing Enterprise Modeling &amp; Simulation</td>
<td>S2020</td>
<td>Systems 2020</td>
</tr>
</tbody>
</table>
## Consolidated Solution Strategy: Develop Tools to Enable Better Designs

Develop tools to enable better designs, through:

- Design automation allowing human designers to work at higher levels of abstraction
- Model-based system verification
- Models and simulations that allow rapid prediction of as-built product performance, reducing the need for physical qualification, prototyping, and pilot production
- Facilitation of concurrent, cross-disciplinary design, development and manufacture
- Models that capture design intent
- Improved tools for sustainability / maintainability / lifecycle analysis
- Models that can be used as trade analysis and decision support tools relating to performance attributes, including manufacturing, operation, maintenance, replacements, environmental and impacts
- Improved design visualization
- Platform based engineering
- Producibility databases and analysis capabilities

### Source CoI | Community of Interest Solution Strategies: Develop Tools to Enable Better Designs
--- | ---
AVM | Launch programs to fundamentally alter the way systems are designed, built and verified, significantly improving the capacity to handle complexity.
AVM | Move to higher levels of abstraction in design, introducing design automation and model-based verification and decoupling the design and build phases of the development process.
AVM | META—a program to develop metrics, a representation metalanguage, design tools, and verification techniques to enable the synthesis of vehicle designs that are correct-by-construction.
AVM | META - develop model-based design methods for cyber-physical systems far more complex and heterogeneous than those to which such methods are applied today; to combine these methods with a rigorous deployment of hierarchical abstractions throughout the system architecture; to optimize system design with respect to an observable, quantitative measure of complexity for the entire cyber-physical systems; and to apply probabilistic formal methods to the system verification problem, thereby dramatically reducing the need for expensive real-world testing and design iteration.
AVM | FANG - Expand the number of contributors in the design process by orders of magnitude—we call this ‘democratizing innovation. To that end, DARPA will develop a collaborative infrastructure for crowd-sourcing vehicle designs, called vehicleforge.mil. Investigate novel mechanisms for credentialing users and for ensuring the integrity of the final design.
AVM | FANG will generate an open source development collaboration environment and website for the creation of large, complex, cyber-electro-mechanical systems by numerous unaffiliated designers—with the goal of democratizing the design innovation process by engaging several orders of magnitude more talent than the current industry model.
OM | Manufacturing design tools:
- Develop design & simulation tools that allow rapid predictions of guaranteed performance in actual manufactured products.
- Create tools that empower fully functional products.
FoF | Comprehensive engineering platforms that enable cross-disciplinary information sharing and the capture and transfer of industrial design knowledge.
FoF | More intelligent models providing details of design intent, as well as with better predictive capabilities to help reduce the need for physical prototyping and the erection of pilot plants.
FoF | Self-organizing, collaborative design environments able to adapt to the needs of different sectors and industries, including facilities for product modeling, decision making, and client-oriented simulation.
FoF | Improved tools for life cycle management of all design information and analysis results.
IM | Building a manufacturing knowledge base for designers: best practices; machine capability / availability; tooling database; vendor database. (Gilson)
IM | Producibility reviews early in the process. (Gilson)
<table>
<thead>
<tr>
<th>IM</th>
<th>Technical bases for both physical and functional interfaces between the components of systems technologies. (IWG-pg 58)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IM</td>
<td>Intelligent tools are needed so that designers can predict the impact of their design approaches on key process and performance attributes, including manufacturing, operation, maintenance, replacements, and environmental impacts. These tools need to show total costs in relation to changes in requirements, so different “what if” scenarios can be explored. Smart tools are needed to aid development of tooling and production strategies. (IWG- pg 64)</td>
</tr>
<tr>
<td>IM</td>
<td>Process models and simulation. (IWG-pg 58)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Implement 3D modeling and simulation to replace build-test-redesign paradigm with model-test-build paradigm. (Harris)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Develop products in the virtual world. Use state of the art visualization. (Harris)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Connect design efforts to the manufacturing capability. (Harris)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Conduct a Grand Challenge project to accelerate the cross-discipline end-to-end model based engineering implementation. (Bergenthal)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Explore a model registry concept; assess and shape applicability of M&amp;S catalog and defense meta data standard. (Bergenthal)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Integrate human factors and ergonomic analysis. (Harris)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Use systems engineering to manage and provide traceability of requirements throughout the life cycle. (Harris)</td>
</tr>
<tr>
<td>SM</td>
<td>Establish a clearinghouse, gateway, and technology transfer platform for community-sourced simulation and modeling tools. (SMP4)</td>
</tr>
<tr>
<td>SM</td>
<td>Application of models and simulations, particularly as decision support tools. (SPMEVOSC)</td>
</tr>
<tr>
<td>S2020</td>
<td>Model based engineering - Modeling and simulation tools for concurrent design, development, and manufacture. (DDRE Jun)</td>
</tr>
<tr>
<td>S2020</td>
<td>Platform based engineering - Architectural and automated design tools to rapidly insert new capabilities. (DDRE Jun)</td>
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<td>S2020</td>
<td>Applying architectural and automated design tools to develop a system structure/platform based on commonality, as well as planned variability. (DDRE Oct)</td>
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<tr>
<td>S2020</td>
<td>Platforms are reusable, reconfigurable, and extensible. (BAH)</td>
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<td>S2020</td>
<td>Implement Platform based engineering through Product Line Architectures (PLAs), which are open architectures that have published, accepted interfaces to components that can be provided by different vendors. (BAH)</td>
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<td>S2020</td>
<td>Virtual Environment for Concept Engineering: Collaboratively, interactively create models of desired system behavior. Develop better tools for concept development &amp; evaluation, Tools for concept validation throughout development, Trade analysis for upgrade options. (DDRE Oct)</td>
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<td>S2020</td>
<td>Develop modeling environments for rapid evaluation of alternative concepts. In particular, models that allow designers to identify unanticipated couplings between domains. (BAH)</td>
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<td>S2020</td>
<td>Develop tools and processes that can provide an efficient and interactive environment so that multiple stakeholders can create a shared mental model during the brainstorming process through the development of a concept of operations model which can be used throughout the lifecycle. (SERC)</td>
</tr>
<tr>
<td>S2020</td>
<td>More effective cognitive concept development environment.</td>
</tr>
<tr>
<td>S2020</td>
<td>Environment for rapid evaluation of alternative concepts.</td>
</tr>
<tr>
<td>S2020</td>
<td>Vehicle to validate the concept throughout the development lifecycle.</td>
</tr>
<tr>
<td>S2020</td>
<td>Vehicle to perform trade analysis for upgrade options.</td>
</tr>
<tr>
<td>S2020</td>
<td>Scalable capabilities for complex systems of systems. (SERC)</td>
</tr>
<tr>
<td>S2020</td>
<td>Develop an open systems engineering environment that allows the system to be built before it is built physically, with full community participation and early consideration of downstream issues. (SERC)</td>
</tr>
</tbody>
</table>
Consolidated Solution Strategy: Enhance Interoperability

Enhance interoperability through:

- Technology development & implementation initiatives, such as:
  - Establishing interface protocols that permit manufactures to seamlessly interface with higher levels of design abstraction
  - Use of standards-enabled CAD/CAM packages
  - Integrated product / service systems
  - Using information modeling to incorporate standard formats for like-domain and cross-domain decision making tools and processes

- Leadership and policy initiatives, such as:
  - Providing a forum for driving all electronic enterprise standards
  - Policy, infrastructure and standards; not mandated common tools
  - Organizing an information backbone of relevant standards
  - Standards for storing and sharing information

<table>
<thead>
<tr>
<th>Source</th>
<th>Community of Interest Solution Strategies: Enhance Interoperability</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFI</td>
<td>Orchestrate a common plan at industry level. Identify common ebusiness interface scenario models. Identify a consistent methodology for work. Normalize the data models and other components. Consistently connect electronic enterprise components to Enterprise Interface Solutions. (AIA EEIC)</td>
</tr>
<tr>
<td>SFI</td>
<td>Provide a forum for driving all electronic enterprise standards. An industry level response is needed to realize the benefits. (AIA EEIC)</td>
</tr>
<tr>
<td>SFI</td>
<td>Organize an “information backbone” composed of information standards (XML, EDI, UML, STEP, PLCS, S1000D), Internet standards (HTTP, HTML, FTP, SMTP), Public/Private Registries (UDDI, DoD XML Registry), Information security (SAML, PKI, TSCP), Web services (UDDI, WSDL, XML, SOAP), and standards bodies (OASIS, UN/CEFACT, ISO, W3C, E3AG) (AIA EEIC)</td>
</tr>
<tr>
<td>SFI</td>
<td>Information backbone built from policy, infrastructure, and standards; not common tools. (AIA EEIC)</td>
</tr>
<tr>
<td>SFI</td>
<td>AIA members will adopt existing standards; influence standards organizations through participation to meet member requirements; develop AIA standards when no applicable standard exists.</td>
</tr>
<tr>
<td>OM</td>
<td>Sustainable business models: Establish interface protocols that permit manufactures to seamlessly interface with higher levels of design abstraction and that the manufacturing processes models, tools and behavior models can be fully integrated into integrating libraries.</td>
</tr>
<tr>
<td>FoF</td>
<td>Integrated product/service systems.</td>
</tr>
<tr>
<td>IM</td>
<td>Paperless and seamless data transfer system. (Gilson)</td>
</tr>
<tr>
<td>IM</td>
<td>Standards for storing and sharing information. (Gilson)</td>
</tr>
<tr>
<td>IM</td>
<td>Using standardized CAD/CAM packages. (Gilson)</td>
</tr>
<tr>
<td>SM</td>
<td>Data interoperability to seamlessly exchange electronic product, process, and project data between collaborating groups and across design, construction, maintenance and business systems. (SPMEVOSC)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Use information modeling to incorporate standard formats to ensure interoperability of like and cross domain decision making tools and processes. (Harris)</td>
</tr>
<tr>
<td>NCM</td>
<td>Standards, such as ISO 10303, that facilitate the exchange and management of product manufacturing information. (Peters)</td>
</tr>
<tr>
<td>NCM</td>
<td>Tools to enhance interoperability between independent firms across the globe, extending to business practices and standards. Manufacturing Data Packages that are more compatible, so a broader range of manufacturing capabilities can be integrated into the supply network. (NCM 2008)</td>
</tr>
</tbody>
</table>
**Consolidated Solution Strategy: Improve 3D Technical Data Packages**

Develop and implement improved 3D Technical Data Packages through:

- Technology development & implementation initiatives, such as:
  - Methods for improved validation of data passed from one software package to another
  - Supporting pilot demonstrations of model-based processes
  - Building the business case (cost justification) for 3D TDP implementation by capturing savings data

- Leadership and policy initiatives, such as:
  - Supporting updates to MIL-STD 31000
  - Evaluating existing relevant standards and practices and revise as appropriate
  - Establishing other relevant standards as appropriate
  - Assisting industry, particularly small and medium sized businesses, in adopting the relevant tools and practices
  - Supporting use of 3D TDPs in defense procurement contracts

<table>
<thead>
<tr>
<th>Source</th>
<th>Community of Interest Solution Strategies: Improve 3D Technical Data Packages</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEMS</td>
<td>Develop ability to fully test “native to neutral” formats across DoD and its trading partners. (H&amp;C)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Harmonize DoD efforts with industry efforts to improve model validation. Currently well coordinated with AIA and ASME, but not with SAE and SME or others. (H&amp;C)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Update MIL-STD 31000. (H&amp;C)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Reach out to industry in order to baseline MBE readiness and raise overall MBE literacy. (H&amp;C)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Initiate pilots to demonstrate model-based processes. (H&amp;C)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Identify and evaluate existing DoD, industry, and commercial TDP standards and practices. (H&amp;F)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Establish current DoD and Agencies policy and guidance for 3D TDPs. (H&amp;F)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Recommend DoD level standard or document required for 3D TDP implementation. (H&amp;F)</td>
</tr>
<tr>
<td>MEMS</td>
<td>DoD Engineering Drawing and Modeling Working Group (DEDMWG) to revise/update standards related to TDPs. (H&amp;F)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Develop and test tools for validating product models. (H&amp;F)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Develop an unambiguous set of requirements defining an acceptable level of model quality for use in contractual documents. (H&amp;F)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Define the data required to construct the business cases / value propositions, and how that data will be captured. (Bergenthal)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Launch a small number of model based contracting pilot projects. (NDIA)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Conduct consensus conference and develop model based engineering common reference model. (Bergenthal)</td>
</tr>
<tr>
<td>MEMS</td>
<td>Develop model based engineering standards roadmap and then develop the standards. (Bergenthal)</td>
</tr>
<tr>
<td>IM</td>
<td>Standardization of 3D MBE requirements. (Gilson)</td>
</tr>
<tr>
<td>IM</td>
<td>Creation of model centric, robust Tech Data Package. (Gilson)</td>
</tr>
<tr>
<td>NCM</td>
<td>Advanced technical data packages (A-TDPs) that provide specific and proven manufacturing processes to be followed, reduce non-recurring engineering time, and shorten production ramp-up. (Peters)</td>
</tr>
</tbody>
</table>
## Consolidated Solution Strategy: Intelligent Manufacturing

Develop tools and methods to implement intelligent manufacturing, such as:
- Metrology tools and methods for real-time handling of manufacturing information
- On and off machine inspection, test, and measurement
- Sensors networks for data capture and machine-to-machine communication for real-time monitoring of material flows and resource use
- Physics-based models that reliably predict the behavior of manufacturing processes
- Equipment and software that is integrated and self-aware (via sensors) so it can recognize its condition and report it to interoperating devices so they can respond appropriately
- Scientific and engineering databases that are available to designers
- Human interfaces that facilitate timely and appropriate human intervention

<table>
<thead>
<tr>
<th>Source Col</th>
<th>Community of Interest Solution Strategies: Intelligent Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>FoF</td>
<td>Large scale testing and validation of robotics-based and other automated manufacturing and post-production automation processes in real-world environments.</td>
</tr>
<tr>
<td>FoF</td>
<td>Laser applications, including ultra-short pulse lasers and adaptive and dynamically-controlled laser-based materials processing systems.</td>
</tr>
<tr>
<td>FoF</td>
<td>New metrology tools and methods for large-scale and real-time handling and processing of manufacturing information.</td>
</tr>
<tr>
<td>FoF</td>
<td>Enabling technologies under the emergent Internet of Things, meaning a network of devices such as RFID, wireless sensor networks, and machine-to-machine communication, significantly contributing to increased logistics efficiency, real-time monitoring of material flows and resource use.</td>
</tr>
<tr>
<td>FoF</td>
<td>Tools supporting the production of smart industrial goods, allowing advanced maintenance technologies and services such as predictive and remote equipment maintenance simultaneously and across different sites.</td>
</tr>
<tr>
<td>IM</td>
<td>Use of on and off the machine inspection / Networked CMM data. (Gilson)</td>
</tr>
<tr>
<td>IM</td>
<td>Test and measurement methods. (IWG-pg 58)</td>
</tr>
<tr>
<td>IM</td>
<td>Predictive tools for integrated product and process design and optimization. Physics-based models that reliably predict the behavior of manufacturing processes. (IWG-pg 63)</td>
</tr>
<tr>
<td>IM</td>
<td>Intelligent systems for manufacturing processes and equipment. (IWG-pg 66)</td>
</tr>
<tr>
<td>IM</td>
<td>Automated integration of manufacturing software. (IWG-pg 68)</td>
</tr>
<tr>
<td>SM</td>
<td>Standardize and enhance industrial plant floor and supply chain data capture technologies. (SMP4)</td>
</tr>
<tr>
<td>SM</td>
<td>Application of integrated monitoring and measurement. (SPMEVOSC)</td>
</tr>
<tr>
<td>SM</td>
<td>Models based on a physics-based understanding of material properties. (SPMEVOSC)</td>
</tr>
<tr>
<td>SM</td>
<td>Equipment and software that is integrated and self-aware (via sensors) so it can recognize its condition and report it to interoperating devices so they can respond appropriately. (SPMEVOSC)</td>
</tr>
<tr>
<td>IM</td>
<td>Scientific and engineering databases. (IWG-pg 58)</td>
</tr>
<tr>
<td>SM</td>
<td>Human interfaces that facilitate timely and appropriate human intervention. (SPMEVOSC)</td>
</tr>
<tr>
<td>NCM</td>
<td>Smart machine integration tools that improve the ability to produce a first part correctly without unscheduled delays. (Peters)</td>
</tr>
</tbody>
</table>
### Consolidated Solution Strategy: Improve Supply Network Integration and Management

Develop tools and methods to improve supply network integration and management, such as:

- **Real-time asset management methods for material costs, routings, and inventories**
- **Support development of Service Oriented Manufacturing (SOM) tools and processes**
- **Networked sensors throughout the enterprise for enhanced communication, planning and control**
- **Communication improvements enabled by software-neutral viewers, technical data exchange standards and tools that facilitate and archive collaboration.**
- **Technologies that provide visibility into the manufacturing processes of the extended supply chain and a common master schedule.**
- **Agility improvements enabled by the distribution of details about supply chain participants and their roles, common contract terms and outcome-oriented acquisition strategies.**
- **Robust engineering change management tools that communicate changes immediately throughout the entire supply chain.**
- **Robust database of suppliers that includes multiple layers of capabilities (machines, processes, ability to collaborate, ability to innovate).**
- **Methods for governing the supply network. Govern a network in which both design and manufacturing are occurring simultaneously at different firms, change is happening in real time, and rapid response is vital to success. Methods for a “self-regulating network” that uses incentives, inhibitors and standards to reward collaboration, innovation and interoperability solutions.**
- **Supplier risk assessment tools that monitor financial viability, and track potential risks such as natural disasters, labor disputes, geopolitical conflicts, etc.**
- **Modeling and simulation of supply networks with large scale optimization**
- **Sourcing tools that streamline the sourcing process, making it easier to solicit more suppliers with less effort while protecting intellectual property.**
- **“Available capacity” matchmaking that allows suppliers to anonymously post available capacity for given manufacturing processes**
- **Streamlined processes for managing and protecting intellectual property**

<table>
<thead>
<tr>
<th>Source CoI</th>
<th>Community of Interest Solution Strategies: Improve Supply Network Integration and Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>FoF</td>
<td>Real-time asset management methods for materials and high tech commodity costs, routings, and inventories.</td>
</tr>
<tr>
<td>MEMS</td>
<td>Use net centricity to ensure the availability of managed information at the right place and time, supporting multifunctional decision making and execution across the extended enterprise. (Harris)</td>
</tr>
<tr>
<td>SM</td>
<td>IT-enhanced and standardized supply networks. (SMP4)</td>
</tr>
<tr>
<td>SM</td>
<td>Networked sensors throughout the enterprise for data collection, data communications, automated control systems, long and short term planning, predictive modeling, optimization, environmental health &amp; safety management. Data fusion and information integration to create useful, accessible knowledge is essential in a network-centric manufacturing environment. (SPMEVOSC)</td>
</tr>
<tr>
<td>SM</td>
<td>Multi-scale dynamic modeling and simulation and large scale optimization. (SPMEVOSC)</td>
</tr>
<tr>
<td>OM</td>
<td>Sustainable business models: Streamlined IP process.</td>
</tr>
<tr>
<td>SOM</td>
<td>Build a taxonomy of services around commodity segmentation strategy. (White)</td>
</tr>
<tr>
<td>SOM</td>
<td>Develop semantic structures for domain-specific, machine-interpretable product and process information that can drive manufacturing services without the need for human mediation of ambiguities. (B&amp;M, pg. 27)</td>
</tr>
<tr>
<td>SOM</td>
<td>Develop smart registries of services that can operate on this information, and mechanisms for discovery and coordination with information that is distributed across the manufacturing community. (B&amp;M, pg. 27)</td>
</tr>
<tr>
<td>SOM</td>
<td>Develop design rules, reasoning engines and resource allocation approaches that can match product and process needs with available services and constraints. (B&amp;M, pg. 27)</td>
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<tr>
<td>SOM</td>
<td>Develop dynamic scheduling tools and automated brokers that can orchestrate supply chain and dynamic production planning solutions faster and better than humans. (B&amp;M, pg. 27)</td>
</tr>
<tr>
<td>SOM</td>
<td>Develop open and scalable interface standards and service level agreements that extend SOA to handle manufacturing information, and wrappers to make legacy systems compliant with the interfaces. (B&amp;M, pg. 27)</td>
</tr>
<tr>
<td>SOM</td>
<td>Develop mechanisms to assure trusted services. (B&amp;M, pg. 27)</td>
</tr>
<tr>
<td>SOM</td>
<td>Build a set of use cases and a road map for SOM – This activity will involve building a road map that guides the rest of the effort to build and launch the SOM infrastructure and provide for meaningful pilots and test cases. The test cases will provide the context for early developments and a means for establishing benchmarks for measuring success. (M&amp;W)</td>
</tr>
<tr>
<td>SOM</td>
<td>Develop the SOM infrastructure – Establish the architecture, standards, and common vocabulary needed to support SOM. Work is needed on open and scalable interface standards and service level agreements that extend SOA to handle manufacturing information as well as wrappers to make legacy manufacturing-systems compliant with the interfaces. The SOM infrastructure will extend SOA concepts to manufacturing equipment and manufacturing processes. Communities of Interest will be formed to work on vocabularies and common process definitions. Explore ways to “lean out” regulatory and contractual issues for service and to expand on the inherent “performance-based” nature of services. (M&amp;W)</td>
</tr>
<tr>
<td>SOM</td>
<td>Imitate Grand Challenges, Proof of concept, and Pilots – The SOM initiative needs a set of public activities to showcase progress through the implementation of proofs of concept and pilots that test and demonstrate the efficacy of SOME-based solutions. (M&amp;W)</td>
</tr>
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<tr>
<th>NCM</th>
<th>Dynamic supplier networks based on common standards, technologies and business processes. (DSN About NCM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCM</td>
<td>Communicative networks that share information throughout the manufacturing supply chain, regardless of disparate systems. Communication improvements are enabled by software-neutral viewers, technical data exchange standards and tools that facilitate and archive collaboration. (DSN About NCM)</td>
</tr>
<tr>
<td>NCM</td>
<td>Coordinated networks that permit supply chain participants to share production schedules and progress throughout the chain. (DSN About NCM)</td>
</tr>
<tr>
<td>NCM</td>
<td>Coordination improvements that are enabled by technologies that provide visibility into the manufacturing processes of the extended supply chain and a common master schedule. (DSN About NCM)</td>
</tr>
<tr>
<td>NCM</td>
<td>Agile networks that can easily be reconfigured from order-to-order with minimal cost and effort. Agility improvements are enabled by the distribution of details about supply chain participants and their roles, common contract terms and outcome-oriented acquisition strategies. (DSN About NCM)</td>
</tr>
<tr>
<td>NCM</td>
<td>Robust engineering change management tools that communicate changes immediately throughout the entire supply chain. (Peters)</td>
</tr>
<tr>
<td>NCM</td>
<td>Robust database of suppliers that includes multiple layers of capabilities (machines, processes, ability to collaborate, ability to innovate). (Peters)</td>
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<td>NCM</td>
<td>Sourcing tools that streamline the sourcing process, making it easier to solicit more suppliers with less effort while protecting intellectual property. (Peters)</td>
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<td>“Available capacity” matchmaking that allows suppliers to anonymously post available capacity for given manufacturing processes. (Peters)</td>
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<td>Supplier risk assessment tools that monitor financial viability, and tracks potential risks such as natural disasters, labor disputes, geopolitical conflicts, etc. (Peters)</td>
</tr>
<tr>
<td>NCM</td>
<td>Methods for governing the supply network. Govern a network in which both design and manufacturing are occurring simultaneously at different firms, change is happening in real time, and rapid response is vital to success. Methods for a “self-regulating network” that uses incentives, inhibitors and standards to reward collaboration, innovation and interoperability solutions. (NCM 2008)</td>
</tr>
<tr>
<td>NCM</td>
<td>Modelling of NCM networks. (NCM 2008)</td>
</tr>
</tbody>
</table>
Develop methods for manufacturing that are more adaptable to changing product requirements, such as:

- Manufacturing methods that apply the adaptation strategies of semiconductor foundries
- Rapid setup and processing
- Methods that allow low-volume production runs with the same economies as high-volume runs
- Processes and tools to make “good enough” parts
- Tools and methods for rapid product and process qualification
- “Plug and produce” connection of automation equipment

<table>
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<tr>
<th>Source</th>
<th>Community of Interest Solution Strategies: More Adaptable Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVM</td>
<td>iFAB complements META’s “fab-less” design capability with a “foundry-style” manufacturing approach.</td>
</tr>
</tbody>
</table>
| OM     | Rapid manufacturing: Develop new manufacturing / fabrication capabilities and models that  
|        |  • Enable rapid setup and processing.  
|        |  • Allow low-volume production runs with the same economies as high-volume runs. |
| OM     | Manufacturing to need:  
|        |  • Provide complete solutions to “the inverse problem” that enable a desired functionality to dictate  
|        |    product attributes.  
|        |  • Provide processes and toolsets to enable fabrication of “good enough” parts. |
| OM     | Rapid qualification: Identify experiments and targeted tests that rapidly optimize part qualification processes. Design for testability. |
| FoF    | Adaptive and fault tolerant process automation, control, and optimization technologies and tools. |
| FoF    | Intelligent production machines and “plug and produce” connection of automation equipment, robots and other intelligent machines, peripheral devices, smart sensors and industrial IT systems. |
| FoF    | Novel methods of interaction with, and automatic tasking of, intelligent cooperative automation and robotic control systems that support flexible, small batch and craft manufacturing. |
| S2020  | Applying product, process, property, environment, mission models to ensure rapid, concurrent, integrated development of adaptable systems. (DDRE Oct) |
| S2020  | Capability on demand - Systems embedded with organic adaption capabilities. (DDRE Jun) |
### Consolidated Solution Strategy: Trusted Systems and Cyber Security

Develop tools to enhance trusted systems (components that are neither counterfeit nor tampered with) and cyber security through:

- Multi-level security in collaboration tools and other open interfaces
- Design methods and tools for system assurance that detect malice or enable self-awareness
- Isolating suspect components, making them not part of the enduring core
- Architectures to make systems less transparent to attackers
- Trustworthiness assessment tools and methodologies

<table>
<thead>
<tr>
<th>Source CoI</th>
<th>Community of Interest Solution Strategies: Trusted Systems and Cyber Security</th>
</tr>
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<tbody>
<tr>
<td>IM</td>
<td>Secure manufacturing systems integration. (IWG-pg 69)</td>
</tr>
<tr>
<td>SM</td>
<td>Scalable, requirements-based multi-level security. (SPMEVOSC)</td>
</tr>
<tr>
<td>S2020</td>
<td>Trusted systems design - Design methods and tools for system assurance that detect malice or enable self awareness. (DDRE Jun)</td>
</tr>
<tr>
<td>S2020</td>
<td>Use Platform Based Engineering tools to design the system to address trust. Isolate suspect components, make them not part of the enduring core. Research the following: -architectures to make systems less transparent to the attacker; -methods, models for implementing trusted system design throughout system lifecycle; -trustworthiness assessment tools and methodologies (DDRE Oct)</td>
</tr>
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</table>
Chapter 5. The Enterprise Transformation Perspective

One of the themes discussed during the AME track at the 2010 Defense Manufacturing Conference was the “socio” challenges of transforming the current defense industry into the envisioned advanced manufacturing enterprise. This theme recognizes that technology development alone will not realize the AME vision; leadership is required to align the incentives of the many stakeholders and push through the needed culture change.

Dr. William Kessler of the Tennenbaum Institute, Georgia Tech, asserts that transforming manufacturing enterprise systems from “as is” to “to be” won’t happen unless the implementation strategy appropriately considers how to operate and govern the advanced manufacturing enterprise as a socio-technical enterprise system. Dr. Kessler cites an analysis showing that 40% of successful industry transformation is “socio,” meaning a combination of executive action (leadership, vision, strategy, acquisitions) and people (culture change, marketing, collaboration, communications, human resources, and training).

Dr. Kessler goes on to describe the Advanced Manufacturing Enterprise as a complex adaptive system, which is characterized as a system:

- that has no single point of control;
- that is composed of independent agents whose goals and behaviors are often in conflict;
- for which adaption, incentives and learning-by-doing tends to result in self organization and patterns of behaviors that emerge (instead of being directed).

He asserts that this reality presents challenges involving a very broad span of required research; a departure from command and control governance and traditional authority structures; integration across the product value streams and the life cycle; increased complexities, and the need to obtain stakeholder commitment to the top level strategy for establishing and deploying AME capabilities. To address these challenges, Dr. Kessler says the AME community must develop the necessary transformational and socio competencies.

Rusty Patterson of the National Council for Advanced Manufacturing also spoke about stakeholder misalignment and to the needed direction to move AME forward. He said that the AME community should:

- Create a vision and strategy that links the roles of all Federal agencies and is informed by all relevant stakeholders.
- Create an “internationally competitive” environment for U.S. manufacturing as the major wealth creating engine of our economy, in order to create/retain/restore jobs.
- Create an integrated, comprehensive, coherent, overarching manufacturing policy.

---

Presenters at the 2009 Network Centric Manufacturing Forum offered other comments on the theme of socio transformation. While their remarks were specifically targeted at Network Centric Manufacturing, their points seem to apply equally well to the entire AME community of interest. Some examples (as quoted from the 2009 NCM Forum White Paper, rather than from directly from the presenters) are offered in the following paragraphs.

Dr. William Rouse of the Tennenbaum Institute, Georgia Tech, said that:

Executives must develop the capabilities to shift from managers of a “command and control” structure to leaders of a self-organizing enterprise. As such, they must focus on improving agility rather than efficiency, establishing performance measurements based on outcomes rather than activities and driving transformation and performance through an understanding of incentives and inhibitions. Furthermore, he explained, they must focus on transforming hierarchical organizational structures into heterarchical (horizontal) networks centered on personal commitments rather than purely contractual relationships. In the transformation journey, leadership must abandon traditional models of organizational design and instead master the incentives and inhibitions that facilitate self organization towards the desired outcomes.

In this forum, Dr Kessler said that, “To move forward, there is an imperative to focus on investigating and fostering new kinds of collaboration and trust that enable NCM strategies. Collaboration and trust are critical to NCM success, regardless of the specific path chosen.”

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Chapter 6. Recommendations

This report brings together two types of recommendations: some for 1) managing the portfolio of AME project investments, and others for 2) leading the AME movement. The primary focus of this AME Strategic Baseline was to inform decision makers on investment opportunities for the AME portfolio of projects. Along the way, however, the referenced documents, subject matter experts, and the advisory panel frequently pointed to solid recommendations for leading the AME movement. Recommendation 1 primarily addresses suggestions for managing the AME portfolio of project investments. Recommendations 2 – 6 primarily address suggestions for leading the AME movement.

Recommendation 1: Invest DoD funds to accelerate implementation of AME practices within the defense industrial base.

Chapters 1 and 2 of this report make the case that DoD should invest funds in developing and implementing AME technologies. Doing so will accelerate the implementation of AME practices and bring tremendous reductions in cost and lead time while improving U.S. manufacturing competitiveness.

What solutions should DoD invest in? The seven Consolidated Solution Strategies in Chapter 4 are a compilation of the over 100 solution strategies quoted from the source material of the communities of interest described in Chapter 3. The Consolidated Solution Strategies are a menu of potential topics to include in a solicitation for AME technology development proposals.

The seven Consolidated Solution Strategies, in no particular order, are the following. The supporting details for each strategy are shown in Chapter 4.

- Develop tools to enable better designs
- Enhance interoperability
- Develop and implement improved 3D Technical Data Packages
- Develop tools and methods for intelligent manufacturing
- Develop tools and methods to improve supply network integration and management
- Develop methods for manufacturing that are more adaptable to changing product requirements
- Develop tools to enhance trusted systems (components that are neither counterfeit nor tampered with) and cyber security

When selecting topics to solicit, government program managers should consider which project ideas may already have been funded (or may be targeted for funding in the immediate future) by government or industry. Of particular note are those projects advocated by the DARPA Adaptive Vehicle Make and Open Manufacturing programs, which are backed by substantial funding and are engaged in acquisition processes at the time of this report’s publication.

The solution strategy topics, as presented in this report, are not scored or prioritized. This is because the research methodology for this report does not lend itself to objectively giving more weight to one solution strategy topic over another. The referenced sources don’t adequately
describe the cost/benefit numbers for any given solution strategy topic, nor do they reveal know
how many experts support each topic or how much weight to give to any particular expert’s
opinion. While some topics are already being worked and others still await initial funding, no
topic is so well-funded already that it should be exempted from additional DoD support.

Every solution strategy topic presented has a constituency of knowledgeable manufacturing
industry professionals behind it, so funding projects for any topic listed here would be
defensible. Likewise, not funding some topics listed here (which is inevitable with the
foreseeable available funding) means that some solution strategies which may be essential to
fully achieving the AME vision will proceed more slowly than they would if they were funded.

This appears to be a situation in which the solution strategy topics all have similar merit, and it
is the quality of the proposals received that should be used to prioritize what to fund. For
example, while “Enhanced Interoperability” and “Improved Supply Network Integration and
Management” may be equally important solution strategies, a proposal from a team of three
major system integrators and some of their key suppliers to demonstrate AME practices would
probably have a higher impact than a small business that wants to write a software package
which may or may not be adopted by customers. The higher-impact of a great proposal should
carry more weight than the priority of the topic it responds to.

The government may determine that there are too many solution strategy topics, relative to the
number of proposals that can reasonably be evaluated or funded. In this case, it is recommended
that a panel of experts (such as the AME Subpanel) be asked which few of the seven
Consolidated Solution Strategies should be included in the first solicitation, and which of the
seven should wait for a later acquisition cycle. Furthermore, the panel of experts could be asked
to prioritize and/or to delete the least compelling topics within each Consolidated Solution
Strategy.

Recommendation 2: Engage with the most appropriate communities of interest and
provide leadership that coordinates their efforts to the benefit of all.

Mr. Eric Mittlestadt, who at the time he spoke in 2009 was the President of National Council for
Advanced Manufacturing (NACFAM), said the following.

Although the development of tools, standards, and processes to support the NCM vision
are underway, they are happening in an ad-hoc manner. The NCM Forum provided the
opportunity to hear status reports on these activities (such as those at Lockheed Martin on
the F-35 program and at Boeing on the 787 program), but no organization is bringing
these pieces together in a way that ensures their compatibility, which could result in a
loose assemblage of solutions that lack the transformative power and cost savings benefits
of an integrated system. We believe that until an empowered organization takes the lead in
establishing an NCM infrastructure, tools and standards may continue in development but
miss opportunities for interoperability. Government and industry should take action on
driving an infrastructure that supports NCM by facilitating the connections and
transactions that enable the formation of efficient supplier networks that replace the rigid supply chains that we know today. \[137\]

While Mr. Mittlestadt was specifically referring to Network Centric Manufacturing (NCM), his comments apply equally well to AME. The “empowered organization” he refers to should be the DoD, because only the DoD has both the leverage of a major customer and the credibility of a neutral party (in an industry otherwise populated largely by competing firms). While every firm that adopts AME practices will benefit from improved competitiveness in the domestic and global marketplace, the DoD has the most to gain in terms of costs avoided and ability to adapt to changing warfighter requirements.

The DoD already has the appropriate organizations in place to lead: the recently established Manufacturing and Industrial Base Policy (MIBP) office and the Joint Defense Manufacturing Technology Panel’s AME Subpanel. Relationships with relevant industry organizations such as NACFAM, NDIA, and AIA are well established. In conjunction with other government and industry stakeholders, an AME executive-level steering committee should be formed, and AME practitioner meetings and conferences should be convened. Together, these organizations should take the lead in advocating policies and standards to support AME implementation.

**Recommendation 3: Apply the lessons of the Quality Movement to implementing AME, and Consult Experts for Guidance on Enterprise-Level Change Management.**

Chapter 3 asserts that AME in 2011 is much like the Quality Movement was in 1993. They share all of the following to a large degree.

- The goals of dramatic reductions in costs and lead time while delivering better products.
- They are populated by several communities of interest that use overlapping (but not identical) approaches to achieving those goals.
- The scope of change, in terms of processes, investment, culture, and the number of organizations that must participate, is enormous.

Everything the prior generation learned from the Quality Movement about implementing change should be applied to the AME movement. In the 1990’s, there were plenty of case studies describing failed attempts to implement quality initiatives. In general, these were not failures of quality tools, but rather, failures to properly manage change. Dr. Kessler of the Tennenbaum Institute (and a member of the study team’s Advisory Panel) correctly observes that a necessary step to implementing AME is addressing the “socio” aspect, which involves applying leadership and people competencies to transform an industry. Properly applying the Quality Movement’s lessons of industry transformation (particularly with regard to executive leadership and culture change) to AME implementation will help overcome this hurdle. The Tennenbaum Institute, and other experts on how enterprise-level change can be successfully managed, should be consulted in order to define more specific strategies for transforming the current defense industry into an advanced manufacturing enterprise.

The list of lessons from the Quality Movement is long, and there is no attempt to describe them all here. One lesson is certainly near the top of the list: change won’t happen without executive-level champions and “change or perish” ultimatums from customers leading the way. This leads directly to the next recommendation.

**Recommendation 4: Engage the support of executive-level champions for AME implementation within DoD and industry.**

For AME implementation to be well underway within 10 years, high-level executives within DoD and industry must become AME champions now. To achieve their buy-in and support, the AME Subpanel and MIBP should work towards very effectively articulating the compelling reasons for implementing AME. Effectively making the case will require describing AME with return-on-investment data (in terms of time and money saved) and without jargon.

Currently, the return-on-investment data (as reported here in Chapter 2) either comes from other industries (bringing the data’s applicability into question) or comes from narrow demonstrations that cannot necessarily be extrapolated to a larger population of implementations. To make the business case to executives, the compelling story of “$X invested will get you $Y back in Z years” must be told convincingly.138

Leaders of the AME movement should also work on how to describe their vision in an elevator speech without using jargon. Terms like “digital thread,” “model based enterprise,” “network centric manufacturing,” “service oriented manufacturing,” “intelligent, integrated manufacturing,” and “above the shop floor,” may be intriguing to industry conference audiences, but they are not self-explanatory. Executives in DoD and industry whose background is not in manufacturing, but who do control relevant policy and funding, will neither understand nor support AME based on descriptions filled with jargon. (Even experienced design and manufacturing professionals who have not been indoctrinated through attendance at relevant conferences, or through reading several AME papers, are likely to make incorrect assumptions about what such terms mean.) This report offers an “executive level” definition of AME in Chapter 1 as a starting point, but this definition is subject to continued improvement. Effective executive-level explanations of what AME is trying to do will feature less jargon, more pictures, more stories, and more numbers. Furthermore, different definitions and descriptions will be more appropriate in different contexts. AME leaders should work towards developing definitions, elevator speeches, diagrams, stories, return-on-investment numbers, and briefing charts so that executives with little manufacturing or engineering background can understand both what AME is, and the compelling reasons for supporting AME investment.

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138 See Chapter 2 for this report’s commentary on what the return on investment might be.
Recommendation 5: Learn in-depth from case studies such as the Boeing 787 and Lockheed Martin F-35 implementations of AME practices.

Both the Boeing 787 and Lockheed Martin F-35 programs applied AME practices to a significant degree in order to manage their global supply networks. Both programs are now suffering from high-profile delivery delays and cost overruns, which makes it likely their cases will be raised for consideration whenever a large future investment in AME is discussed. There is an opportunity to learn from these cases: what went right, and what should be done differently next time?

The lessons should be learned and documented for defense manufacturing industry decision makers to ensure their continued support for AME. Advocates need to be able to tell the story that AME practices were not the problem, they were just not yet mature enough to be the 100% solution. With sponsorship, AME will mature and address the problems that really did create cost overruns and delays.

Other companies with AME implementation success stories should be studied as well. John Deere, Caterpillar, Gulfstream, and Procter & Gamble may provide informative case studies.

Recommendation 6: Develop a dashboard of metrics for AME implementation.

Although one of the key goals of implementing AME practices is to reduce costs, metrics in addition to cost should be developed. Experience with the Quality Movement showed that it was challenging to measure cost savings due to quality initiatives even as low down in the organization as the facility level. Measuring cost savings at the enterprise level due to AME initiatives will be exponentially more difficult. Other metrics should be used to show that AME implementation efforts are making progress.

AME leaders need a scorecard to show whether or not the enterprise is better off each year. Leaders should develop several metrics that can be reasonably tracked and plotted on a radar or spider chart. This is another area in which the Quality Movement might be consulted for guidance, as it utilized many measures of goodness such as cycle time, yield, and rework. These metrics were often easier to quantify and track in real time than cost was.
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Appendix A. Inputs from Subject Matter Experts

The team was referred to several subject matter experts to ask, “What are your recommendations for new AME initiatives that the DoD should invest in?” Answers were received in various forms: telephone interviews, briefing charts, and email responses. A summary of the answers received is in the following sections.

Paul Huang, Army Research Laboratory

Paul Huang and John Christensen provided their input in the form of a briefing titled, “Moving from Drawings to Model-based TDPs: R&D to Policies to Practice,” dated February 10, 2011. Mr. Christensen said that other individuals had also contributed to writing the briefing. This briefing was designed to be used as a “road show,” to be presented to several audiences in the months ahead. This briefing was used as source material for the “Manufacturing Enterprise Modeling and Simulation” section of Chapter 3.

Rusty Patterson, NACFAM

Rusty Patterson is the President of the National Council for Advanced Manufacturing (NACFAM) and a member of the study team’s Advisory Panel. Publications by Mr. Patterson and/or NACFAM are referenced in many places in this report. In addition, Mr. Patterson offered the following points in a phone interview.

- To support AME initiatives, the government should act above the DoD level to put in place manufacturing policies and an overarching infrastructure. The issues are cross-cutting, and commercial industry should be included because commercial industry is so big.
- A real concern is China stealing U.S. intellectual property. The government needs to better enforce free and fair trade rules to level the playing field.
- The government should explore ways to grant government subsidies to industry to implement AME technologies and practices, like other countries do.
- The AME workforce will require workers trained in science, technology, engineering, and math (STEM). Doing so will help to keep jobs in the U.S. American workers need to be re-trainable, embracing K-80 learning instead of K-12.
- In order to be competitive in a networked environment, industry must cooperate to compete. Perhaps DoD should look into setting up a model similar to Sematech, so that the U.S. can employ a public/private partnership to make AME a reality and lead the world in innovation. No one company can solve this; a joint initiative is needed.
- Part of the collaboration issue is government regulation that frowns upon collaboration between competitors (such as Lockheed Martin and Boeing). Ways must be found to permit collaboration without letting too many lawyers get in the way.
- A roadmap for an appropriate public-private partnership to make AME a reality should be developed. A case study to learn from is the Lean Affordability Initiative (LAI), which involved Massachusetts Institute of Technology (MIT) as an “honest broker” that helped secure proprietary data. In this role, MIT helped overcome policies and
procedures that made it difficult for Northrop Grumman and Raytheon to collaborate on the Global Hawk program. LAI was specific action rather than just “talking in generalities.” LAI implemented specific projects that were a vehicle for addressing barriers, constraints, and drivers.

Dr. Al Sanders, Honeywell Corporation

Dr. Sanders wrote several briefings and papers discussing design and modeling for producibility, and those were referenced in the “Producibility Modeling” section of Chapter 3. In addition, Dr. Sanders wrote up the following inputs specifically for this report.

I spent some time going through the documents you sent me and have attached a matrix that illustrates some key gaps in the current investments. The biggest observation is that 90% of the current investments are geared around tech data packages, standards and interoperability, and model-based approaches to automate and link CAD/CAM/PLM environments. Obviously my push has been to have targeted investments in system design approaches and quantitative producibility analysis tools which does come across as an area that is currently receiving very limited investments. The NDIA AMEC committee I am leading with Brench will be putting together detailed research and investment roadmaps to better guide investments in these areas over the next year but I see a huge opportunity to "jump start" the AME portfolio by structuring a research thrust around developing an analytical basis to quantitatively assess manufacturing efficiency, complexity, and risk at the production line, factory, and enterprise levels.

The motivation here is that on the engineering side of product development there is an analytical basis that allows the performance, efficiency, and energy consumption of physical systems that include engines, airframes, avionics, radar, etc. to be quantitatively assessed such that feasibility and risk of proposed design concepts can be assessed. On the industrial engineering side of the equation however, there is no such analytical basis and as a result nearly all of the current investments focus on streamlining and automating existing processes and/or making supply chain and manufacturing data visible to design teams. Needed is an analytical basis for predicting and comparing alternative manufacturing processes, manufacturing value streams, supply chain concepts, as well as the overall manufacturing enterprise performance over the product life cycle comparable to what is currently done for physical weapon systems. This analytical basis would provide a means to not only evaluate alternative manufacturing and supply chain concepts for feasibility, but also provide an analysis-based means to identify where new AME technology investments will have the highest rate of return.

Now I am not quite sure what the right metrics, measures, performance, and efficiency measures but think this would be a good RFI/RFP topic to solicit ideas from leading researchers in the field so the AME sub-panel could pick and choose to fund the ones that made the most sense. That being said here is my stab at crafting some RFI/RFP descriptions around some key focus areas that I think could provide the AME sub-panel with some focused projects to get the ball rolling while Brench and I develop and flesh out the AMEC producibility M&S roadmaps over the next several months.
**Topic 1: Analytical Manufacturing Enterprise Complexity and Performance Measures**

Problem Statement: Today's supply chains such as that used to manufacture, build, and sustain defense weapon systems are globally dispersed dynamic entities with numerous sub-tier suppliers which conventional SCM approaches fail to effectively manage risk. Currently there are no known analytical performance measures that can be used to characterize and predict the underlying supply chain complexity, manufacturing efficiency, and risk associated with the transactions and hand-offs that occur across multiple supply chain tiers. Needed are analytical frameworks and measures that can be used to quantify the overall manufacturing enterprise performance from a life cycle factory operating and support cost standpoint that can be used to identify weak links and high impact improvement opportunities to simplify and streamline the overall enterprise performance. This would include but is not limited to analytical definitions or supply chain and manufacturing process complexity driven by product and industrial base characteristics, definitions of overall enterprise manufacturing efficiency that accounts for loss mechanisms such as yield fallout, in-process rework, quality control and oversight, quality escapes, including the cost of global transactions and supplier-to-supplier process capability variations associated with "as is" and "to be" supply chain designs under different demand scenarios and capacity bottlenecks.

Benefit: Having an analytical basis to quantify and characterize the manufacturing enterprise performance would enable an analysis driven approach to help identify future AME projects and investment needs to address inefficiencies in current supply chains, provide a quantitative means to estimate anticipated improvements associated with the proposed projects and/or alternate supply chain concepts, and most importantly provide an overarching framework that would integrate the output of M&S-based approaches for manufacturing risk and efficiency prediction.

**Topic 2: Industrial Enterprise Manufacturing Life Cycle Cost Prediction**

Problem Statement: Current life cycle cost (LCC) prediction methodologies focus on the cost to the total ownership cost to the external customer who is procuring the weapon system. In fact, nearly all requirements that drive life cycle cost are related to what the external customer is willing to pay, with little emphasis given to what cost will be incurred over the life cycle of the product by the manufacturer. At best material and conversion costs based on similar to designs are used in the LCC predictions along with some simple learning curve estimates of how the cost can be reduced as a function of the volume and learning rate. Neglected in this simple approach are how "hidden factory" mechanisms such as yield fallout, quality control and oversight, in-process rework, quality escapes, process capability shortfalls, obsolescence, etc. impact the factory conversion costs, affordability, system sustainability, and environmental sustainability over a 30-50 year product lifecycle. These costs typically manifest themselves in factory overhead rates and when problems are found after the product is fielded usually result in price escalations since the profit margins of the manufacturers are being eroded by unplanned for and unanticipated manufacturing inefficiencies and risks during the early
development activities. Needed is an "internally focused" manufacturing life cycle cost view that examines all of the factory operating and support costs over the lifetime of the product similar to the mature processes that currently exists for "externally focused system life cycle cost view that examines all of the customers development, procurement, and operating and support costs.

Benefit: Having an analytical basis to identify and quantify the impact of manufacturing cost, quality, and cycle time considerations on life cycle cost would allow manufacturing costs and risks to be better understood and hence predicted during early development planning activities so that alternative industrial base concepts could be evaluated based on their ability to minimize manufacturing costs and risk over the product life cycle. This capability would also guide improved cost model development by providing a means to quantify and understand how "hidden factory" costs erode profit margins and ultimately lead to price escalations after the system is fielded.

Topic 3: Affordability Requirements Flow Down and Analysis Framework

Problem Statement: There is a tremendous push within the DOD to treat affordability as a requirement in the system development process with should cost and would cost prediction receiving a lot of attention. The main gap keeping affordability from being treated as a requirement with the same rigor as other system requirements is that nearly all current cost modeling approaches are bottoms up estimates and as a result cost is an output of the process rather than an input. Approaches advocated cost as an Independent Variable (CAIV) has been around for over a decade but what is still missing is an analytic framework and methodology to define, analyze, and allocate appropriate affordability requirements such as material cost, conversion cost, manufacturing cycle time, yield, tolerance ranges, etc. in a top down manner as part of the systems engineering process. And since a rigorous, well defined, and structured process does not exist for setting affordability requirements at each level in the system hierarchy, cost is usually considered as an afterthought after all performance requirements have been met. Needed is an analytical basis and framework that would allow affordability requirements to be defined, analyzed, and the feasibility tracked with the same level of rigor as is used when evaluating performance-based figures of merit as part of the systems engineering process.

Benefit: Having a structured analytical basis to set affordability as a requirement as well as evaluating the feasibility of proposed design concepts in meeting cost targets is a critical first step in setting should cost targets and performing would cost scenario analyses. This capability would also allow manufacturing considerations and their impact on affordability to be directly integrated into early systems engineering activities where there is the largest opportunity to influence acquisition cost.
David Stieren, NIST Manufacturing Extension Partnership Program

David Stieren provided both email input and a phone interview. These inputs are summarized below.

(Here are) some of my thoughts with you about appropriate DOD investment possibilities relating to MBE.

- MBE technical infrastructure development can only take implementation so far. I see a glaring hole right now in the space of acquisition and contracting policy calling for/requiring the use of MBE for DOD procurements. This currently does not exist, as far as I know. Time and attention needs to be focused on putting in place acquisition policy such that the transition to MBE will be required as the basis for the DOD approach going forward. In other words, I believe that until MBE is the stated requirement in contracting and procurement actions, its widespread implementation will be slow—regardless of how robust the technical infrastructure may be. Suppliers will make the shift when the market demands they do so.
- TRUST is a huge issue across the supply base relating to suppliers’ implementation of MBE.
  - Model validation must be rigorous and required for 3D models to be used as the master in DOD design and production operations. All organizations that touch data throughout the design, production, and sustainability life cycle must trust the data contained in the models.
  - As suppliers operate in MBE environments, their capabilities to work with MBE data and integrate it into their processes should be certified. Doing this will create trust throughout the various tiers of the supply chain that operations are occurring such that model fidelity is not degraded as models get consumed at different points in the production life cycle.
- Supplier awareness needs to continue to be cultivated. The supply base is broadly agile and capable, and the continual increased awareness of the supply base regarding MBE—especially how the DOD will implement MBE and what that means—will make the transition to MBE occur more smoothly and effectively.

The items above summarize what I would say are the most pressing areas I see at this time—realizing that my view point is very much based upon the perspective of how the supply base can and should implement MBE for DOD design, production, and sustainability.

In a phone interview, Mr. Stieren offered the following additional points.

- Transformation depends on customer requirements. While some “enlightened” firms might proceed ahead of formal requirements, DoD must implement appropriate policy and program offices must impose contractual requirements before the supply base will make the needed changes.
- When crafting policy and requirements, it may be best to study “best practices” of one or more industry champions.
• DLA needs to play an important role in the transformation to the use of 3D TDPs, because every national stock number item needs to eventually be part of the 3D TDP process.

• A supplier certification program that evaluates each supplier’s capability with regard to 3D TDP’s should be created. An MBE capability scale of levels 0-6 is already in place. Certification should not be mandatory, but it would be good business.

Dr. Mark Traband, Penn State University

Dr. Traband provided a response compiled from inputs from engineers at ARL Penn State and Kevin Carpentier of CNST/ATI. Rebecca Clayton of Navy ManTech referred the study team to Dr. Traband, who listed the following initiatives.

New AME Subpanel Initiatives:

1) Improved Tools to Estimate and Measure Schedule Adherence and Cost Control During the Weapons Systems Acquisition Process - Major weapons systems are cancelled (FCS, EFV), or are at risk/under great scrutiny (DDG 1000, JSF) as much or more due to cost and schedule issues as they are due to technical risks. Schedule slips have a dramatic impact on cost. Tools and methods to better estimate schedule early in the acquisition process (pre-Milestone A) and to mature and track the schedule as the acquisition progresses through the process are needed. Estimated funding required: $5M.

2) Reducing the Span Time of Weapons System Production – Studies have shown that driving labor content out of the manufacturing process can have a significant, positive effect on production costs, but reducing the span time of manufacturing process, even without reducing labor content, can produce even greater savings. As an example, reducing the span time for a Virginia Class Submarine from 84 to 60 months reduced the cost by $200M per hull. This savings is largely attributable to the marching army (fix/overhead costs) of the engineering and infrastructure costs that are avoided by minimizing the build span. Other service platforms with higher production rates could also benefit. This topic is tightly coupled with #1. Estimated funding required: $4M.

3) TOC Estimation and Validation Methods – While requirements exist to estimate lifecycle costs for weapon systems early in the acquisition process, these estimates are difficult to validate and little measure of uncertainty in the estimates are generated. This often leads to design and manufacturing decisions being made will less than full visibility to their impact on lifecycle cost. Providing better TOC estimation methods and also tools to track these costs throughout the lifecycle will provide a better basis for future design and acquisition decisions. Estimated funding required: $3M.

4) Maintenance of the TDP throughout the Lifecycle – The full 3D TDP needs to be available throughout the lifecycle of a weapon system. Currently this is not the case. As an example, the baseline deliverable for the digitally designed Virginia Class Submarine CITIS (Contractor Integrated Technical Information Service - a contractor provided service for electronic access to and delivery of contractually required digital data) includes drawings, not 3D models of the design. This will reduce the efficiency of the
Navy personnel responsible for the maintenance of the vessels throughout their life. However, this issue will not be solved by just acquiring the original 3D data. As well as the as-designed technical data, for Navy platforms it is also necessary to have access to the as-built and as-maintained technical data. This means that improved methods to collect, archive, and access this information are required. Estimated funding required: $15M.

5) Knowledge Capture/Knowledge Retention - With an aging work force both in the production and maintenance of weapon systems, improved methods for capturing, maintaining, and using process knowledge need to be developed and deployed. Estimated funding required: $2M.

6) Feedback of Maintenance Knowledge into the Design – The span times for the development of Naval weapon systems are years and decades. Designers may have the opportunity to work on only a few new designs in their career. In addition, there is no structured means for providing feedback to those designers regarding the maintainability of design once they are built. Evidence suggests that many of the same design decisions (mistakes) are made in subsequent ship classes that have serious cost and schedule consequences for the maintainers. Providing a formal means of capturing the ramifications of these decisions and feeding back alternatives to designers will reduce TOC. A topic in this area may be more appropriately referred to as Design for Production/Design for Affordability. Estimated funding required: $2M.

7) Improved Decision Support Tools for Planning and Scheduling – The planning and scheduling of tasks in the shipbuilding and maintenance environment is an inordinately difficult task. COTS tools do not adequately address the complexity and scope of the requirements. Because of this manual intervention and adjustment of the plans and schedules is the norm, generally resulting is sub-optimal task execution and schedule delays. Providing improved decision support tools that span the range of scheduling requirements (from hours to days to years ahead) will dramatically reduce the cost of building and maintaining Navy platforms. Estimated funding required: $5M.

Paul Villanova, U.S. Army ARDEC

Paul Villanova provided the following comments during a phone interview.

- We should develop standards and specifications in this area. There should be standards for data exchange and interoperability; supply chain standards; process standards; and standard criteria for evaluating producibility. Standards-based technologies should be supported.
- Technology development with demonstrations and pilot programs are needed. The AME Subpanel should work to ensure all AME projects align with and enhance each other, rather than operating independently.
- DoD should encourage greater collaboration among other government agencies to move AME forward.
• The AME Subpanel has links to other subpanels. For example, intelligent machining relates to both AME and Metals subpanels.
• It is challenging to quantify the ROI for AME. Companies such as Gulfstream (represented by Jim Deleporte) tell strong success stories about using AME practices, but as a competition-sensitive metric, they choose not to say how much they are saving.

Roy Whittenburg, U.S. Army ARDEC

Mr. Whittenburg is a contractor employed by UTRS, currently supporting Steve Luckowski at U.S. Army ARDEC, and until recently, an employee of BAE. Mr. Whittenburg co-authored one of the source documents referenced in the “Manufacturing Enterprise Modeling and Simulation” section of Chapter 3, and offered the following points in a phone interview.

• AME investments should be made into standards for pushing 3D model data through the supply chain. Right now, not enough suppliers are able to seamlessly take 3D data into their production systems.
• Mr. Whittenburg is currently working on E-Sourcing, which is an add-on to Product Lifecycle Management (PLM) and Enterprise Resource Planning (ERP) systems that would help suppliers interface with requests for quotation.
• Culture change is an issue. We should change contractual language to influence programs and require that we get the 3D data we need.
• We should look more at capturing process definitions in 3D models.
• We should work to break down barriers between depots.
• The AME Subpanel should ensure that its project selection process is open, transparent, and collaborative.
• Technology investments areas of particular interest are:
  o Additive manufacturing;
  o Robotics and automated assembly as an integrated system;
  o Augmented reality to help humans do their jobs.
• Implementing relevant standards will require both a push from the government side and pull from defense industry system integrators.
Appendix B. Synopsis of Recent and Current ManTech Projects in Support of AME Goals

There were several DoD-sponsored AME projects ongoing or recently completed as of February 2011. The following sections briefly summarize the projects for which information was either provided by the project sponsors or readily available on the sponsors’ web sites.

Defense Advanced Research Projects Agency (DARPA)

DARPA Adaptive Vehicle Make Program Portfolio

Issue: The Defense Advanced Research Projects Agency (DARPA) has embarked on a series of programs aimed at revolutionizing the way defense systems and vehicles are made. Titled Adaptive Vehicle Make, the portfolio has three principal objectives: to dramatically compress development times for complex defense systems such as military air and ground vehicles, to shift the product value chain for such systems toward high-value-added design activities, and to democratize the innovation process.

Initiative: DARPA’s Adaptive Vehicle Make is a portfolio of programs that address revolutionary approaches to the design, verification, and manufacturing of complex defense systems and vehicles. This portfolio includes the following programs: Instant Foundry Adaptive through Bits (iFAB), vehicleforge.mil, Fast Adaptable Next-Generation Ground Combat Vehicle (FANG), and Manufacturing Experimentation and Outreach (MENTOR) efforts.

The ongoing META program seeks to develop model-based methods for the design, representation, and formal verification of complex cyber-electro-mechanical systems such as defense vehicles in a “fab-less” environment. The ultimate goal of the META program is to make a dramatic improvement on the existing systems engineering, integration, and testing process for defense systems. META is not predicated on one particular alternative approach, metric, technique, or tool. Broadly speaking, however, it aims to develop model-based design methods for cyber-physical systems far more complex and heterogeneous than those to which such methods are applied today; to combine these methods with a rigorous deployment of hierarchical abstractions throughout the system architecture; to optimize system design with respect to an observable, quantitative measure of complexity for the entire cyber-physical systems; and to apply probabilistic formal methods to the system verification problem, thereby dramatically reducing the need for expensive real-world testing and design iteration.

The top-level technical objectives of the META program are as follows:

- Develop a practical, observable metric of complexity for cyber-physical systems to enable cyber-vs-physical implementation trades and to improve parametrization of cost and schedule;
- Develop a quantitative metric of adaptability associated with a given system architecture that can support trade-offs between adaptability, complexity, performance, cost, schedule, risk, and other system attributes;
- Develop a structured design flow employing hierarchical abstraction and model-based composition of electromechanical and software components;
• Develop a component and manufacturing model library for a given airborne or ground vehicle systems domain through extensive characterization of desirable and spurious interactions, dynamics, and properties of all constituent components down to the numbered part level; develop context models to reflect various operational environments;

• Develop a verification flow that generates probabilistic "certificates of correctness" for the entire cyber-physical system based on stochastic formal methods, scaling linearly with problem size;

• Apply the above framework and toolset to design, manufacture, integrate, and verify an air and/or ground vehicle of substantial complexity 5X faster than with a conventional design/build/test approach.

The Instant Foundry Adaptive through Bits (iFAB) effort looks to lay the groundwork for the development of a foundry-style manufacturing capability—taking as input a verified system design specified in an appropriate meta language—capable of rapid reconfiguration to accommodate a wide range of design variability and specifically targeted at the fabrication of military ground vehicles.

The principal objective of iFAB—coupled with META—is to enable substantial compression of the time required to go from idea to product through a shift in the product value chain for defense systems from “little m” manufacturing (i.e., fabrication) to the other elements of “big M” Manufacturing (i.e., design, customization, after-market support, etc.). Such a shift requires significant de-coupling of production from the other phases and facets of “big M” Manufacturing so as to enable its commoditization. One might term this the “foundry-style” model of manufacturing. This model is an anathema to the current defense industry trend of tightly coupling design and prototyping through multiple design-build-test-redesign iterations. In fact, the iFAB vision is to move away from wrapping a capital-intensive manufacturing facility around a single defense product, and toward the creation of a flexible, programmable, potentially distributed production capability capable of accommodating a wide range of systems and system variants with extremely rapid reconfiguration timescales.

The specific goals of the iFAB program are to rapidly design and configure manufacturing capabilities to support the fabrication of a wide array of infantry fighting vehicle models and variants. Parallel efforts titled vehicleforge.mil and Fast Adaptable Next-Generation Ground Combat Vehicle (FANG) seek to develop the infrastructure for and conduct a series of design challenges intended to precipitate open source design for a prototype of a next-generation infantry fighting vehicle analogous to the Army’s Ground Combat Vehicle (GCV). The iFAB end vision is that of a facility which can fabricate and assemble the winning FANG designs, verified and supplied in a comprehensive metal language representation with META tools.

It is anticipated that the iFAB capability is likely to result from the amalgamation of existing fabrication capabilities from a model library that characterizes the salient attributes of each modality of fabrication: cost, speed, range of applicability, speed of reconfigurability, etc. The resultant factory or foundry need not be manifested as a single facility co-resident under one roof. It can be a virtual aggregation of distributed capabilities, sequenced and tied together into a single resultant product flow. The emphasis of the initial, 12-month phase of iFAB will be on tools for foundry design and (re)configuration.
The principal objective of the vehicleforge.mil effort is to generate an open source development collaboration environment and website for the creation of large, complex, cyber-electro-mechanical systems by numerous unaffiliated designers—with the goal of democratizing the design innovation process by engaging several orders of magnitude more talent than the current industry model. The initial phase of the program will last 12 months and culminate in the operational deployment of vehicleforge.mil. The development of complex software systems has benefitted significantly from the ability to leverage crowd-sourced innovation in the form of open source code development.

Open source software “forge” sites—a key enabler to the success of the open source development paradigm—facilitate collaborative development, source tree maintenance, and version control while allowing participation by a large number of independent programmers. Examples include SourceForge and GNU Savannah. The application of open source methods to the development of electromechanical systems has been more limited. And while one can identify several successful examples, they are largely confined to the development of relatively simple products (e.g., Quirky for consumer product design), or have required significant back-end engineering effort to turn product concepts into detailed designs (e.g., Local Motors for custom cars). vehicleforge.mil aims to significantly expand this capability for defense systems by employing a general representation language—being developed under the META program—that is rich enough to describe a broad range of cyber-electro-mechanical systems, yet formal enough that the system can be “compiled” or verified in some manner when a design change is made to some element or aspect of it.

The Fast Adaptable Next-Generation Ground Combat Vehicle (FANG) effort will seek to exercise META, iFAB, and vehicleforge.mil capabilities in a series of design challenges of increasing complexity, seeking to leverage fab-less design, foundry-style manufacturing, and a crowd-sourced innovation model—and culminating in a complete design and fabrication of an infantry fighting vehicle in the span of one year.

The Manufacturing Experimentation and Outreach (MENTOR) effort is aimed at engaging high school students in a series of collaborative distributed manufacturing and design experiments. The overarching objective of MENTOR is to develop and motivate a next generation cadre of system designers and manufacturing innovators, and to ensure that high school-age youths are exposed to the principles of modern prize-based design and foundry-style digital manufacturing. The end vision for MENTOR is the development of user-friendly, open-source tools to enable the utilization of conventional social network media (e.g., Facebook apps) for the purpose of collaborative distributed design and manufacturing across hundreds of sites and thousands of users. This capability will be accompanied by the deployment of an inexpensive, heterogeneous set of digitally-programmable manufacturing equipment (e.g., 3D printers for various materials) to 1,000 high schools globally. Prize-based design and manufacturing challenges would then enable clusters of schools to team and compete against one another in the development of cyber-electro-mechanical systems of moderate complexity such as go carts, mobile robots, small unmanned aircraft, etc.
Digital Manufacturing Analysis, Correlation and Estimation (DMACE) Challenge

**Issue:** Advances in digital manufacturing (DM) may address cost and time constraints associated with manufacturing the complex components required to support the Department of Defense mission. With the ongoing development of DM, a better understanding of the capabilities and limitations of DM is needed.

**Initiative:** The Defense Advanced Research Projects Agency (DARPA) Digital Manufacturing Analysis, Correlation and Estimation (DMACE) Challenge is a competition designed specifically to use crowd sourcing to advance knowledge of the potential capabilities and limitations of DM.

Within the Challenge, competitors will develop models that predict the output properties of products created by a DM machine based on corresponding machine inputs. The Challenge could be solved by applying any of a wide variety of engineering, mathematic or other approaches to predictive modeling.

“Widespread acceptance of DM components requires first that we determine whether predictive correlations exist between DM settings and resultant product properties,” said Gill Pratt, DARPA program manager. “If a predictive correlation model is found, there is potential to change defense manufacturing significantly. If a manufacturer can predict the reliability of a component part with a high degree of certainty, DM could be used for all sorts of system components.”

The DMACE Challenge requires participants to develop the most accurate DM output predictive models given a set of input parameters for two different computer aided designs (CAD): one for a sphere (digitally manufactured with titanium) and another for a cube (digitally manufactured with polymer). Data describing the input settings for a particular digital manufacturing process and the resultant output of structural tests will be distributed by DARPA online. Input setting data may include, but is not limited to device control parameters, material composition, and CAD files. Output test data may include, but is not limited to structural load test results such as stiffness, strength, and displacement data. These data sets will be provided on the DMACE website to registered individuals and teams.

Defense Wide Manufacturing Science & Technology Program

3D Technical Data Package

**Issue:** The DoD recognized that it had a problem with their TDP requirements, which are focused on 2D, not 3D, data. The existing policy and guidance for TDP requirements is not clear for PM/PEOs. MILDTL-31000C does not clearly define 3D TDPs and there is no uniform DoD guidelines or standards that define a 3D TDP and specifies the content requirements.

**Initiative:** To try and address this issue, OSD embarked on an initiative to identify and evaluate existing DoD, industry and commercial TDP standards and practices in order to establish current DoD and Agency policy and guidance for 3D TDPs. Through this analysis, a recommendation has been put forth to establish a DoD level standard or document requiring 3D TDP implementation.
Benefits: Implementation of 3D TDP requirements will prove beneficial to the warfighter. A clear 3D TDP definition will allow for a more streamlined acquisition process for weapon systems. This will lead to overall program reduction in weapon platforms lifecycle costs, providing for faster delivery from concept to production and the ability to reuse data in the product lifecycle, while enabling easier use of technical publications and manuals.

3D TDP Validation

Issue: A recent Office of the Secretary of Defense (OSD) memorandum emphasized that quality prototyping efforts and manufacturing process knowledge are critical aspects of system acquisition product sustainability. Unfortunately, many legacy systems and new designs do not consider manufacturing planning in the acquisition process. Likewise, the added pressures to meet cost, schedule and performance in design often cause designers to not consider manufacturability until very late in this process. This can significantly delay full-scale production and sustainability of parts in the field. A specific lack of connectivity between manufacturing process information and design information can significantly impact the ability to produce parts.

Initiative: To address this issue, OSD ManTech sponsored a project with the U.S. Army Research, Development and Engineering Center (ARDEC) to prove out the concept of extending the traditional Technical Data Package (TDP) to include modern manufacturing process data files (MPDF). OSD has identified this game-changing concept with a goal to demonstrate that a supplier using qualified manufacturing processes can create a qualified part faster than traditional methods and that process can be replicated across the industrial base.

For a legacy weapon system like the M2 machine gun, the design has been proven, but the ability to manufacture certain parts has been lost. For this reason the gun barrel extension, which is a complex part with tight tolerances, was chosen as the pilot part. It has been traditionally difficult to source. Likewise, it is in high demand and the current supplier is only able to produce 300 parts a month while the current need is for 700 parts a month.

The project included a demonstration of extending the traditional technical data package as follows:

- Definition and creation of the MPDF data for the selected parts
- Prove out the MPDF data by sourcing a part to the industrial and the organic bases.
- Analyze time and cost savings versus traditional methods.

Benefits: Through using the MPDF, the results of the project showed a significant savings of time, as shown below:
<table>
<thead>
<tr>
<th></th>
<th>gun barrel extension</th>
<th></th>
<th>shank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>250 hrs manufacturing run time</td>
<td></td>
<td>44 hrs manufacturing run time</td>
</tr>
<tr>
<td><strong>Legacy Hours</strong></td>
<td><strong>Hours Saved</strong></td>
<td><strong>Percent</strong></td>
<td><strong>Legacy Hours</strong></td>
</tr>
<tr>
<td>Sourcing</td>
<td>81.20</td>
<td>51.03</td>
<td>62.8%</td>
</tr>
<tr>
<td>Engineering</td>
<td>162.00</td>
<td>136.70</td>
<td>84.4%</td>
</tr>
<tr>
<td>Manufacturing Setup</td>
<td>120.50</td>
<td>80.00</td>
<td>66.4%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>363.70</td>
<td>267.73</td>
<td><strong>73.6%</strong></td>
</tr>
</tbody>
</table>

There were additional benefits that became apparent as this experiment was conducted, including:

- The total cost savings for a production order of all the parts was 45%.
- Two out of three suppliers said they would not have bid on the part without the MPDF.
- The suppliers indicated that having the MPDF reduced their risks allowing for a better price per part.
- Two new industrial base suppliers became qualified as part of the implementation, thus increasing the capacity and speed to manufacture M2 parts to support the war fighter.
- Gun barrel extensions and shanks were manufactured at 2 new suppliers who had never created these parts. These parts passed first article inspection, test firing, and magnetic particle inspection with no rework required.

**Integrated Design Environment For Visualization (IDEV)**

**Issue:** Incompatible Computer-Aided-Design systems and the inability to share effective design models in a collaborative environment result in costly producibility issues and unforeseen engineering changes. Long acquisition cycles, development cost overruns, and field support issues are problems that continue to impact DoD procurements.

**Initiative:** One way to address these problems is implementation of the Model Based Enterprise (MBE), which will enable future designers and customers to identify design issues early in the process, explore and evaluate options and then implement solutions before they drive cost. The benefits of an MBE are significantly enhanced through implementation of a visualization environment.

The purpose of the Improved Design Effectiveness Through Next Generation Visualization (IDEV) is to develop capabilities to merge CAD data from various formats into an immersive, 3D environment and make changes within that environment and transfer those changes back to the authoring CAD tool.

The goal of this applied research and development project is to create commercial software to integrate design tools with immersive visualization. Integration of immersive visualization capabilities with design tools improves the ability to identify design issues that drive cost in
manufacturing and in the field. Creating the capability to pull disparate CAD models together into a virtual environment and allowing multiple sites to simultaneously view the same virtual prototype models provides the opportunity for collaborative design reviews that identify and resolve issues early in the development process.

This will allow design teams to more effectively implement innovative solutions to demanding performance requirements using virtual prototypes. The result will be fewer design iterations (reduced acquisition time), fewer hardware prototypes (reduced development cost) and more robust fielded designs (fewer support issues). The capability for bi-directional linkage from Computer Aided Design (CAD) tools into next generation visualizations (virtual reality) is currently at a Technology Readiness Level (TRL) of 3. This project is expected to increase the robustness of the technology to a TRL of 6 or higher. The foundation of the work is an innovative use of technology matured by the gaming industry and clever integration with state-of-the-art developments in the CAD industry. The expected customer benefits will be accomplished through the development of capabilities to merge CAD data from various formats into a single representative model within an immersive, three dimensional (3D) environment, make changes to the design within that visualization environment and transfer modifications back to the original CAD tool. This effort will develop and demonstrate improved visualization capabilities on a product common to the Joint Stand-Off Weapon (JSOW) and Small Diameter Bomb II (SDB II) Programs. The ultimate goal is to transfer technology that supports integration of systems with immersive visualization into industry to benefit all future DoD development activity. Transfer will occur by the commercialization of any associated intellectual property (IP) of the developed integration and visualization software by a third party.

Two possible solutions to link CAD & Virtual Reality will be explored:

- Utilization of a standard data format (STEP).
- Conduit software package that runs parallel with the CAD package.

The analysis will provide a recommended solution for further testing, implementation, evaluation, and couple VR user interfaces into CAD packages. The overall goal is to develop the capability for multiple sites/suppliers to simultaneously view the same virtual prototype, providing low cost VR system software that will allow the users to share VR images in remote locations via a tool that is affordable to lower tier suppliers.

Benefits: The perceived benefits of implementation of such a capability include more robust designs due to utilization of immersive VR technology and collaborative design reviews involving team members from across the supply chain. This will allow for faster deployment to the field and fewer design iterations resulting from earlier identification of design issues, resulting in reduced product cost through virtual versus physical prototyping. In addition, the improved designs will reduce life-cycle sustainability costs.

Simulation Chain Risk Modeling and Simulation Using Flow Equivalent Servers (FES)

Issue: The purpose of the Flow Equivalent Servers (FES) project is to develop a reliable but simple model to replace detailed simulation of individual suppliers in supply chains. The end
goal of these new capabilities is to provide robust analysis for DoD acquisition supply networks with a reduction in analysis cost and time.

**Initiative:** For DoD acquisition supply networks that have difficulty predicting and analyzing risk in material flows and schedule integration, this project develops the basic methodology of Flow Equivalent Servers, a statistically based model that can replace a single facility simulation in a hierarchical simulation of a supply chain. Unlike previous approaches that are either static or require manual and special-purpose model integration, the FES approach is dynamic, flexible, manageable, supports different tools, and can be automated.

Initial results show that the FES can be a very accurate tool. In the FES Phase I effort, the FES team has shown the technical feasibility of the approach through the following tasks.

- Developed and tested FES models for suppliers that accurately reproduce their simulated or observed schedule and capacity performance.
- Demonstrate feasibility to extract FES from representative manufacturing simulation models.
- Defined a neutral data format for the exchange of FES models between discrete event simulation software packages.
- Defined the requirements for a FES model configuration management and linking system based on the requirements of multiple DoD acquisition programs.

Due to the current limits of production theory, the team has to develop a novel approach to achieve this goal. A new model is derived for approximating the cycle time and WIP behavior of a factory simulation, based on newly observed properties in general queuing networks. Using these properties, the newly developed models outperform existing approaches, and give very small approximation errors.

In consideration of the data availability and confidentiality issues likely to arise in supply network analysis, two approaches are adopted, referred to as black box and white box. The black box approach assumes the team does not know the details of the simulation models but only the input and output data. The white box approach assumes we can examine the details of the simulation models, therefore, more accurate approximate results can be achieved.

The current models have only considered the single product scenario. In practical manufacturing systems, a production line may deal with multiple products and the cycle time of each product may need to be estimated individually. In Phase I, the team has developed the cycle time approximate model for single product scenario. The cycle time approximate models for multiple products are left for Phase II.

For an assembly line, in Phase I, the team mainly focused on the total cycle time instead of the WIP profile. In order to compute the WIP profile for an assembly line, they had to know the detailed cycle time in each part of an assembly line. The data requirement and analysis is more than the White Box approach defined in Phase I. The more detailed WIP profile analysis is left for Phase II.
The current models developed in Phase I mainly focus on the impact from randomness effect. Although the impact from parallel batching has been considered and incorporated into the model, the thorough discussion on the synchronization effects (such as shift schedule, dispatching rules and serial batching) is not done.

**Risk Analysis for Next Gen Supply Chain (RANGER)**

**Issue:** DoD has recognized that small variations in cost, quality, or delivery at any stage of the supply chain can lead to major problems during weapon system production. Current measurement systems are unable to define or quantify risks to enable effective management of supply chains, leaving a vulnerability that unforeseen failures may negatively impact performance.

DoD supply chain operations have become globally distributed supplier networks with a wide range of diverse operations, personnel, and logistics that bring continually changing needs and thus, disruptive changes. Supply chains are now exposed to unprecedented global risks and uncertainties (environmental, political, etc.). In addition, because they are also exposed to increasing complexity, rapidly changing technology and shorter product life cycles, industry needs effective supply chain management practices that enable sustainability, higher resilience, adaptability, and reconfigurability.

**Initiative:** In this highly complex environment, a holistic and systems-based approach to supply chain management (SCM) is required to increase supply network sustainability and resilience by mitigating risks. DoD defines SCM as, ‘…an integrated process that begins with planning the acquisition of customer-driven requirements for materials and services and ends with the delivery of material to the operational customer, including the material returns segment of the process and the flow of required information in both directions among suppliers, logistics managers, and customers’ (DoD Supply Chain Management Implementation Guide). This definition stresses planning, sourcing, maintaining, and delivering the material and service requirements to the operational customer (warfighter) conducting DoD operations. These activities must be managed comprehensively because the DoD supply chain is part of a much larger system-of-systems.

The RANGER project was to develop, implement, test and validate a software framework and algorithms to provide more effective supply chain risk management for the DoD industrial base. The objective of this project was to improve the predictive capability for risk modeling in supply chain operations through a generic software tool on an interoperable platform, which can be customized for dual use according to Department of Defense (DoD) and commercial application needs. **RANGER** efforts were organized into three task areas (1) Analysis; (2) Model development and validation; and (3) Demonstration further divided into eight activities. Phase I focused primarily on five of these activities which involved identifying sustainable supply chain risk drivers and their relationships, establishing methods for measuring these risk drivers, their validation, mapping the existing supply chain and the risk drivers affecting the supply chains to identify interrelationship and modeling and simulation of the sustainable supply chain risks. Based on the research conducted, a comprehensive, multi-faceted and customizable risk modeling software was developed on a MS Excel platform. This software (RADAR) was
then used to conduct risk analyses with two test-bed partners: GE Aviations’ Madisonville, KY plant and the Joint Defense Attach Munitions (JDAM) supply chain for Boeing.

In phase I of the RANGER program, the team identified and categorized over 120 risks to the performance of a program arising from supply chain operations. To capture and evaluate these risks, the team created a causal model that can be represented as a Bayesian Belief Network (BBN). The team developed BBNs for two industrial scenarios – Boeing’s JDAM missile program and GE Aircraft Engine’s turbine manufacturing plant. Using these models, they validated the approach to risk analysis using an Excel model. In phase II, the team migrated to a commercial software system for evaluating BBNs. Under RANGER this software will be augmented with a front-end editor to simplify the capture of the BBNs and associated probability data. The team will validate and demonstrate the use of this approach in industrial settings at both Boeing and GEAE.

The RANGER initiative analyzed current supply chain practices, interactions and risk contributors, and efficiency parameters. The RANGER project focused on developing quantitative modeling for the supply chain to identify and model the impact of variation in events to provide a better predictive capability. Model-based enterprise management for next generation manufacturing requires this predictive capability, along with uncertainty analysis and associated cost models. Optimized supply chain risk models were developed by using trade-offs to balance conflicting process performance measures. RANGER demonstrations with industry partner test beds (Boeing and General Electric (GE)) validated the predictive models.

RADAR was validated using the two test-beds to perform risk analysis using internal data gathered from the companies. The tool was also highly received by various other potential users due to its versatility in performing comprehensive multi-tier quantitative supply chain risk analyses, lacking in existing commercial software.

**Benefits:** The warfighter will benefit from supply chain risk management improvements that yield lower costs, better availability of products, longer useful product life, and improved operational planning. By gaining a clearer understanding of the customer’s long term needs, the military and industry will gain improved planning capabilities (e.g., manufacturing, information technology, and workforce), better material resource procurement and inventory management, and improved capabilities for design of replacements for obsolete parts, among others.

**Cost Modeling for Enterprise Transformation (COMET)**

**Issue:** Present systems/methods do not integrate cost modeling with both design and manufacturing operations.

**Initiative:** The purpose of the Cost Modeling for Enterprise Transformation (COMET) is to provide real-time cost estimates in support of design trade studies and risk analysis at all levels of design and system integration. The COMET project developed, demonstrated, and validated technologies and processes to integrate cost modeling with both design and manufacturing operations. It demonstrated the feasibility of driving cost models from Computer Aided Design (CAD) data:
• Converting CAD models to Adobe 3D, accessing the critical features
• Demonstrating feasibility of driving cost models from actual shop-floor performance
  information.
• Extracting actual manufacturing data from the Manufacturing Execution System (MES)
  map the MES data into the team’s high-fidelity cost model that has been modified to
  accept it.

Projected platforms for use are the C-17, F-18 and 747.

Benefits: Preparation of estimates will require much less time while ensuring that estimates are
accurate and complete, thereby improving affordability of U. S. weapon systems, reducing
production and lifecycle cost, and reducing development and implementation schedules. The
successful execution of the COMET project reduces the risk that cost estimates will exceed
program budgets by ensuring that cost models are integrated with design and manufacturing
tools to support real-time trade studies, and critical design feature sensitivity analysis.

Model Based Enterprise - Certification of 3D MBD as Product Master

Issue: 3D model data is not currently approved within DoD for use as “Master” product data.
There are no approved processes or guidelines within DoD for validating 3D product data
integrity or certifying 3D model data for approval as the master data reference. Coupled with
that is the fact that re-entry of product design data is a major source of errors, delays, and excess
costs.

Initiative: This project will perform 3D MBD data validation requirements analysis, develop a
MBD data validation framework, and test the framework using an MBD product model. The
goal is to demonstrate certification of 3D MBD, using existing vehicle data, and publish MBD
data validation guidelines/specifications.

Benefits: The 3D Model Based Definition (MBD) acquisition process will reduce lead time for
platform development and spare parts delivery. 3D MBD has been demonstrated in pilot
programs to reduce manufacturing and operation costs by making data available throughout the
product’s lifecycle which can be applied to DoD systems to:
• Enable block upgrades
• Improve access to data
• Improve data quality
• Reduce delivery time from Concept to Production
• Eliminate data re-entry errors
• Develop tech pubs and manuals directly from design data
• Provide design data directly to provisioning
• Enable faster spare parts acquisition.
Smart Machine Platform Initiative (SMPI) Study

Issue: The DoD has a need for timely and affordable acquisition of DoD machined components. However, machine shops generally do not operate as an integrated entity. The shops have been slow to adopt process modeling as a planning tool. The DoD believes that the reuse of processing data can be done better, but the communication between proprietary sensors and machine controllers needs to be improved.

Initiative: This project entailed:
- Identifying and evaluate existing DoD, industry and commercial SMPI technology and practices
- Updating 2004 SMPI roadmapping document
- Identifying technology gaps where modest investment will help to complete overall integration to reduce cost and lead time for machined parts.

Benefits: This initiative will lead to faster and more efficient production of weapon system component parts. This will lower the cost of parts. There will also be less parts shortages and fewer nonconforming parts. This will allow for faster delivery from concept to production.

Improving Manufacturing Supply Chain Design and Resiliency through a Reusable Modeling and Simulation Framework

Issue: The inability of manufacturing supply chains to respond quickly to unplanned demand or to quickly reconfigure themselves when disrupted significantly impacts the ability of the DoD to get needed equipment in the hands of the warfighter at a time when it is most needed.

Initiative: This initiative involves conducting qualitative primary research with sample supply chains and supplemental secondary research on modeling data. The objective of this project is to produce new ways to improve supply chain performance with a standard, reusable framework for modeling the design, assembly and coordination of manufacturing supply chains. These frameworks will be useable by supply chain or program managers without modeling skills, at any size business. The model frameworks developed from this analysis will allow users to consider complex supply chain data and relationships, enabling smarter decision-making without requiring the user to have modeling skills. These demonstrations will involve key steps, including:
- Challenge #1: Designing a supply chain for a desired outcome, which includes: gathering “As-is” data, creating the “To-be” scenario, developing the model and delivering outcomes. This enables evaluation of sourcing scenarios that improve responsiveness and reduce total ownership cost.
- Challenge #2: Supply chain war-gaming, which includes: gathering “As-is” data, creating the “To-be” scenario, developing the model and delivering outcomes. This allows users to “war-game” supply chain disruptions and evaluate risk mitigation scenarios.

Benefits: The benefits to DoD from Challenge #1 is that it will improve manufacturing supply chain responsiveness, delivering materials to the warfighter faster regardless of whether the
demand was planned or unplanned. Challenge #2 will improve manufacturing supply chain resiliency, so that materials needed to support the warfighter can be delivered on time regardless of disruptions. In both cases, costs and obsolescence can be reduced, freeing those monies to be devoted to other programs supporting the warfighter.

**Producibility Modeling during the Acquisition Process for Cost and Complexity Reduction**

**Issue:** Major DoD weapon programs are over cost and schedule. Not enough attention is paid to cost and producibility early on and throughout development. Cost modeling tools are not understood or applied in mainstream engineering. True ramifications of production costs and issues are not realized until late in programs when cost of change is highest.

**Initiative:** This initiative analyzes 5000.02 acquisition phases to understand how AP modeling can be applied to maximize cost and complexity reduction. It looks at tools development and tailoring, examining ways to enhance existing commercial AP modeling tools with DoD specific metrics in order to develop a DoD acquisition roadmap tool to promote and guide the use of AP through all phases. In the demonstration phase, the tailored AP modeling tools and methods will be applied on current development of DoD onboard vehicle power systems to realize total cost benefits to government and validate tools and methods. The goal is to develop a modeling capability to account for mixed variant production lines. This capability will enable a clear view of cost and complexity across a base architecture, then across variant architectures. The model shall then reveal which variants to focus on for AP, and/or show clear producibility advantages to some designs, allowing a team to evaluate refinements of a design. A customizable math-driven applications tab will also be developed that will allow the user to create unlimited custom fields. These fields will interact with certain data fields that already exist within Design Profit. These math tabs will be savable and synchronized to other users. In addition, a program Producibility and Confidence Index assessment will be developed that will be generated from key metrics that effect cost, producibility, complexity, technology risk, manufacturing risk, value added parts, process steps, and other key variables. The program Producibility and Confidence Index will allow a quick assessment into program success and will be a comparable metric across design alternatives.

Another facet of this project is to develop an “AP Roadmap for DoD Acquisition Phases” This roadmap will help guide and track the user to the relevant detail and modeling levels appropriate against the milestones and major events in the 5000.02. The roadmap shall be a graphical user interface (GUI) which will let the user know what type of data is expected throughout the development phase and how these should relate to key milestones within the acquisition process identified in DOD Instruction 5000.02.

A partner with a critical program within DoD, such as the on-board vehicle power (OBVP) program with the U.S. Army and U.S. Marine Corp for HMMWV platforms, will then be identified. The tailored tools and methods for cost reduction will be applied to this platform. The intent is to use the OBVP program to demonstrate the AP tools and methods and apply lessons learned to the roadmap.

**Benefits:** The benefits to DoD that will be derived from this effort are earlier understanding of cost and complexity, which will promote designs that are more producible, less complex and
more reliable. Better AP modeling will flesh out issues while cost of change is lowest. Higher confidence and knowledge of production will lead to right-first-time, on-schedule manufacturing. The warfighter will benefit by receiving more advanced technology under tightening DoD budgets. Less complex weapons will improve soldier effectiveness and reduce logistics lifecycle costs.

**MT Connect Notification/Alarms Tool Kit**

**Issue:** Industrial/depot production capacity has a direct impact on the warfighter in the form of cost and schedule. Unscheduled downtime accounts for as much as 50% of all losses in production capacity and as much as 13% of revenue losses due to scrapped parts. Automated notification of machining issues do not exist.

**Initiative:**
This project supports development of open source monitoring, measurement, analysis, and optimization/control tools for discrete parts manufacturing. The collection of accurate data can be used to improve production efficiency, enhance shop floor control systems, and improve the management of facility assets.

**Benefits:** The benefits reaped through this endeavor include improved manufacturing efficiency with reduced downtime. The number of scrapped parts and rework will be reduced. More reliable and predictable machining of parts will be realized. Prognostic maintenance of machines will lead to reduce down time and enable open source applications related to machine tool maintenance.

**Army ManTech**

**Digital Depot Manufacturing and Model –Centric Collaboration Environment**

**Issue:** Using conventional Technical Data Packages (TDPs) based on traditional drawings, the Army’s sustainment activities are forced to manually re-create the data for use in downstream activities. Furthermore, acquisitions based on traditional practices take extended periods, prolonging the time to mission.

**Initiative:** With $11M in Army ManTech funding, the Digital Depot and Model Centric Design projects, which began in 2004, were developed to address these issues by refining the process called Model Based Enterprise (MBE). This process maximizes the reuse of the original 3D Computer Aided Design model. By reusing this digital model, much of the manual effort and cost/time associated with them can also be reduced.

The Model Centric Design team has developed a process that organizes data within the models so that it can be easily understood by all of its users. This also allows the information contained within to be extracted programmatically to facilitate the design reuse. In short, this set of processes can:

- Reduce non-recurring engineering and manufacturing by at least 50%
- Reduce the time to mission by 50 – 60%
• Allow sustainment activities to be performed from a TDP prior to receiving the first vehicle.

The Digital Depot program has been the center of technology transfer for this effort. In a series of efforts at both Red River Army Depot (RRAD) and Letterkenny Army Depot (LEAD), the team successfully created a local center of competency. This project was based on the use of DELMIA tools for manufacturing process simulation with the goal of generating Shop Work Instructions for the Bradley Fighting Vehicle’s transmission rebuild activity. This goal was realized by enabling a Model Based Environment (MBE) at the depot. The team successfully created a model based work instruction for the Bradley Cross-drive Transmission and GMV Kits at RRAD & LEAD respectively. RRAD has also used this technology to virtually lay out various assembly lines prior to actually having to build. Another aspect of this project was a comprehensive supply chain assessment of their capability to use a 3D TDP. This assessment found that over 60% of the suppliers were capable of using the model in place of a drawing. This program focused on reforming the way TDPs are created, received and used by the acquisition and sustainment community.

**Benefits:** This Model Based Environment will enable RRAD to be prepared to use model based technical data packages from weapons system OEMs in the future. The overall result will directly support the warfighter through sustainment of weapons systems; with an eye on the design of a lean re-manufacturing process. The end result is the reduction in time to mission for all future programs, thus getting and maintaining critical assets to the warfighter quicker without sacrificing quality.

**Smart Machine Platform Initiative**

**Issue:** Today, there is little capability to achieve model-based control of processes except for a single, or possibly a few, select parameters. Machine modeling that has been done has been designed to relate to ideal conditions, as opposed to incorporating real-world effects with uncertainty. DoD hopes that the smart system initiatives will solve all of the challenges -- not just the trivial. Response to the grossly abnormal occurrence is the challenge.

In most machine operations, a significant amount of data is generated, but there is no good mechanism to utilize the information. Data are usually not time-stamped nor is there any means to correlate the machine condition data and the process data, rendering the information as non-actionable. The initiative's plan concludes that the majority of the data gathered is ultimately lost and represents a significant opportunity for productivity increases and achieving the goal of first part correct.

**Initiative:** The Smart Machine Platform Initiative (SMPI) is an industry, government, and academic program to develop the enabling technologies necessary to allow manufacturing equipment to make decisions based upon acquired knowledge to produce a first part correct without unscheduled delays.

The government-funded initiative is collaboration among commercial firms, government agencies and a variety of machine tool and equipment vendors. The program grew out of two
workshops sponsored by the National Institute of Standards and Technology -- a Smart Machine Workshop in 2000 and a First Part Correct Workshop in 2002. This is a multi-year program managed by TechSolve, the Cincinnati-based Manufacturing Extension Partnership center.

The project's objective is to provide better information that will enable management to achieve the goal of making parts better, faster and at a lower cost. This program is sponsored by a coalition of key manufacturing trade associations, including NTMA, AMT, research organizations, government laboratories, and academia, and it supports research for the development of next generation of internal sensing and control systems that create instructions and integrate them, in real time, into manufacturing processes. The end goal of this technology is "first part correct" manufacturing that reduces costs, waste and production delays.

Technology developments being considered for this program span all areas of equipment design and control (i.e., software, materials, sensors, etc.) The Smart Machine Platform Initiative technology is being developed to monitor and control intricate manufacturing processes in real time, and will serve as the foundation for the next generation of precision manufactured goods. Three examples of technologies developed in the Smart Machine Platform Initiative that are being used at many contract manufacturers: preprocess tool path verification and optimization, tool condition monitoring, and on-machine probing. Assessments of these technologies and their capabilities have proven that they dramatically improve part cycle time and quality.

The first three years of funding were used to survey and validate technologies, so that nothing was wasted in reinventing what existed, proving that the technologies worked on machines and together, and demonstrating them. Funding in the fourth and final year will be used to optimize the technologies and push them to manufacturing, while continuing to make sure the mergers of the technologies are done correctly and smoothly.

In SMPI's technology plan, the initiative is described as a reinvention of the basic manufacturing environment, enabling dramatic improvements in the productivity and cost of designing, planning, producing and delivering high-quality product within short cycle times.

In Phase One, which concluded in December 2005, NCMS members Cincinnati Machine, Caterpillar and Advanced Technology Services collaborated with the Red River Army Depot and Cherry Point Naval Depot in implementing four proof-of-concept "Smart Machine" installations focused on maintenance support functions.

Additionally, the pilot project defined specific, achievable objectives for the subsequent Phase Two project. This is the current initiative that is intended to lead toward a more advanced, intelligent, next-generation factory.

The current Phase Two project expanded the pilot project's original four sites to nine depot and industrial partner sites. In addition to further demonstrating smart machine functionality on a broad mix of applications, an objective of Phase Two is to demonstrate a means of providing secure management access to the shop floor data produced by the installations. It entails installing the infrastructure of a variety of new and legacy machine types to allow the equipment to automatically monitor and log their 24/7 condition in a consistent fashion. The data will then
be processed into concise, factual information that can be conveniently and securely accessed, even from remote locations, to enable managers and support personnel to optimize factory asset performance.

In the initiative's technology plan, the basic machine tool is moving from being a passive asset with a single operator, to an element, or node, in an electronically integrated environment where the three basic attributes of a machine tool are pulsed for information: its availability, capacity and capability. The vision: the machine tool of tomorrow will interact with the design functions, macro- and micro-planning, the verification of quality, and the scheduling and management of product flow.

In addition, tomorrow's machine tool will have an active role in its maintenance and contribute to problem solving and learning for the optimization of the process it performs. It is envisioned that, in an integrated enterprise, the machine tool could evolve to be a peripheral device in the computer network.

The plan calls for the machine tool to be a smart platform for manufacturing operations. Capabilities are to include the detection, reaction and correction of deviations. By enabling the capability for first product correct, the machine tool will eliminate much of the trial-and-error associated with a new part or process.

The primary technology goals for smart operation and control are based on instantaneously sensing the condition of the machine, workpiece and the tool. Comparisons to a process model will determine if adjustments are needed.

The initiative's plan does not call for a completely autonomous maintenance strategy. Instead, when action is required, the enterprise is alerted with instructions about what action is needed.

The drive toward smarter machine tools is not a challenge confined to individual machines and their controls. At the same time that efforts are being made to integrate the connectivity and performance of a sector of the economy, its business strategies must accommodate how that affects brand differentiation.

**Benefits:** Among the benefits noted in Phase One was a reduction in manufacturing process variation in a rubber compression molding application and an improvement in process efficiency of a diesel engine transfer line through better insight into equipment utilization and effectiveness.

Project participants also cited several other key benefits. These include further improvements in process efficiency, process health monitoring, and process variation reduction. Other noted benefits include implementation of automated maintenance management systems and development of algorithms for facilitating predictive functions.

**Network Centric Prototype Manufacturing**

**Issue:** Currently, ESA technical data is “2-D Official”—drawings are Adobe.pdf records or C4 Drawings. The U.S. Army’s drawing of record is a two-dimensional (2-D) drawing with a three-
dimensional (3-D) model provided for reference only. 3-D digital data, when available, is not released to vendors as “official” data—files are considered for information only. This is the case even though the Engineering Services Authorities (ESA) has been building 3-D models for several years for both new systems and legacy platforms. The perception is that a portion of the industrial base is unable to utilize 3-D Computer Aided Design (CAD) models (in reality, most suppliers do have this capability); the Defense Logistics Agency (DLA) continues to provide 2-D drawings when acquiring legacy parts. Vendors must recreate 3-D data from 2-D official data to ensure that parts will be compliant to TDP. The re-creation of 3-D data by vendors costs time and money in quoting, manufacturing and quality.

Three trends are converging to make it important for the Department of Defense (DoD) through the DLA to support 3-D models as the files of record:

1. Technology advancements have made 3-D CAD tools ubiquitous in the industrial base.

2. The Standard for the Exchange of Product Model Data or STEP has matured to the point that it is supported by all major CAD tools. Similarly, 3-D viewers have advanced in their capabilities to support most CAD file formats.

3. The Model Based Enterprise (MBE) is gaining momentum as a business model that best supports the long product life cycle of Department of Defense (DoD) programs. MBE requires the use of 3-D models.

In addition, the creation of a 3-D “official” model is required to leverage the OSD investment in the ARDEC – M2 project and the creation of Manufacturing Process Data Files (MPDF).

To make the 3-D model the “official” format, there is a need to understand the business practices that are currently in place with the buyers at the DLA and the ESA to determine what enhancements and/or changes will be needed to support 3-D models from the initial Request for Quote (RFQ) through First Article Inspection (FAI). There is also a need for all parties (DLA and the Industrial base) to have confidence in the validity of the 3-D model and its association to the 2-D drawings.

**Initiative:** This project piloted the manual validation of the 3-D models based on the U.S. Army Tank-Automotive and Armaments Command (TACOM) modeling and drawing standards.

This initiative undertook updating the SA technical data environment to achieve a 3-D official business practice for storing data and sending data to vendors. A candidate parts list (Army and DLA) and process was established that will migrate 2D to 3-D official environment for DLA acquisition usage. Then, a demonstration of the 3-D data validation process (NIST) was staged, so that the link between 2-D data and 3-D is certified for storage.

In Phase I of the Network Centric Manufacturing (NCM) project with the U.S. Army Research, Development and Engineering Center (ARDEC) Prototype Integration Facility (PIF), the concept of extending the traditional two-dimensional (2-D) Technical Data Package (TDP) to include three-dimensional (3-D) models and modern Manufacturing Process Data Files (MPDF) was established. The project demonstrated that a supplier using qualified manufacturing processes can create a qualified part faster and at a lower cost than the traditional method. It demonstrated the value of a 3-D model and associated manufacturing data in enabling the industrial base to quote, engineer and manufacture hard to source parts more quickly and less expensively.

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To leverage these results, a Phase 2 project was established with ARDEC, the Defense Logistics Agency (DLA), the Manufacturing Extension Partnership (MEP) network, and the National Aeronautics and Space Administration (NASA). A pilot process was demonstrated using 3-D models and data as part of a proposed DLA acquisition process to the industrial base. A manual validation of the 2-D drawing to 3-D official model process was required to provide confidence around the use of this data. Project results included:

- Documented the “as-is” and “to-be” DLA procurement processes for the delivery of 3-D models
- Selected ten small arms critical need National Stock Numbers (NSNs), identified to have long lead times or hard to procure, to pilot through this process
- Processed three NSNs with 28 total parts through the manual validation process, comparing the 2-D drawing to the 3-D model.
- Commenced the sourcing process for two NSNs.

A single point of entry into the industrial base was piloted as part of this project with a small subset of the national MEP network. Catalyst Connection, the Manufacturing Extension Partners (MEP) Center for southwestern Pennsylvania, developed and implemented a supplier qualification program and request for quote (RFQ) process for ARDEC known as the Small Manufacturers Defense Initiative (SMDI). Catalyst Connection coordinated with two other MEP centers (NJMEP from New Jersey and TechSolve from Ohio) to participate in the 3-D “Official” ESA Data Environment project. These three MEPs are representative of the national MEP network. For this project, each MEP identified a minimum of ten suppliers with the capabilities to review the technical data and ultimately to manufacture the parts. The team developed a repeatable process that may be applicable to all MEPs or suppliers in the future so others can participate in the program.

The intent was to find qualified suppliers as part of a future goal to establish a national framework. Project results included:

- Identified three MEP centers and an initial group of industrial base suppliers to review the technical data and capability to manufacture the NSNs
- Sent the 2009 Model Based Enterprise (MBE) capabilities assessment to the suppliers
- Held site visits at six of the selected suppliers, two in each MEP area
- Trained/on-boarded 43 new suppliers on tool use
- Commenced the sourcing process for two NSNs.

This successful proof of concept demonstration served as the basis for ARDEC’s intention to expand the utilization of additional MEP centers as a supply chain resource.

Another demonstration was held to show the interoperable supply chains between the NASA and ARDEC. There is a need for interoperable supply chains between federal agencies that can easily share technical data, including manufacturing process information. This project task demonstrated how 3-D data can also provide interoperability between the Department of Defense (DoD) and National Aeronautics and Space Administration (NASA) and identify issues that exist for interoperability to be realized.

At the national level there is a need to maintain a strong and healthy industrial base.
• For the DoD, during periods of war, there are surge demands placed on the industrial base for spare parts to support the warfighter. What if NASA suppliers could provide parts to support surge?
• For NASA, the gap between the Shuttle program and future programs will likely result in an erosion of the NASA supplier base, including knowledge and skill sets. The greater the gap, the greater the risk and cost for future programs. What if DoD parts demand could keep these suppliers healthy and ready for a future NASA program?
• These peaks and valleys in demand impact the ability of both agencies to acquire products in a timely and cost-effective manner. Significant demand swings also adversely impact the health of the supplier base, creating additional risk from loss of those suppliers.

The nature of the parts required by these two agencies can be quite dissimilar. NASA parts are designed for the extreme environment of space. The quantity per part is very low and the emphasis is on quality over cost. Complete traceability is maintained for every part to enable root cause analyses in the event of a failure. Many parts are only used once and then replaced.

Many DoD parts, on the other hand, have a need for reliability and longevity in extreme earth-based environments such as the desert, jungle or arctic. Thousands of these parts are required monthly with a significant emphasis on cost control. Traceability on a specific part is not as critical in this application.

For all of these differences, there are still a significant number of similarities between the parts. Each are highly engineered high precision mechanical parts required to deal with the extreme environments. Each utilizes similar manufacturing processes, equipment and materials.

This demonstration focused on Robonaut and M2 Machine Gun parts, identifying any technical and policy issues that need to be addressed to realize the benefits of interoperability. The results of this demonstration included:

• Interagency supply chains between NASA and the U.S. Army can be created to successfully manufacture parts
• Specific interoperability issues have been identified.

Benefits: This initiative is supposed to benefit the warfighter by reducing lead-times and the cost of critical weapon spares. This will be achieved by changing DLA’s 2D to 3D official data procurement process environment. In addition, it will demonstrate OSD’s vision of enterprise manufacturing, supply chain responsiveness and interoperability. Shared inter-agency supplier bases will increase agility to better handle unexpected fluctuations in supply and demand.

A Phase 3 project may be undertaken to leverage activities from Phase 1 and 2, particularly:

• Further pilot a Manufacturing Extension Partnership (MEP) framework for a national network of suppliers with a single entry point, with a larger pool of MEPs
• Gather metrics from Phase 2 sourcing events; obtain feedback from suppliers on the process and on the use of the 3-D model data
- Pilot an extension to the DLA 339 process to maintain and update 3-D models and the associated Manufacturing Process Data File (MPDF) data with the Engineering Service Authority (ESA)
- Engage current NSN manufacturers of record and understand the business case around 3-D models.

Navy ManTech

Mid-Tier Shipyard Advanced Planning and Facility Analysis Toolset

**Issue:** The U.S. shipbuilding industry continues to face the challenges of building ships at estimated cost, in many instances based on limited design information and long design and construction lead times. Increased vessel complexity is recognized as one of the contributing factors of the cost escalation. To respond to cost reduction market pressures, industry must strive to minimize excess ship variation by providing cost effective options to the customer while satisfying demand.

**Initiative:** Design for Production (DFP) methodologies have been proven to be an effective tool to reduce design complexity. The latest round of benchmarking of U.S. yards identified DFP as a leading recommended investment area.

Bollinger Shipyards collaborated with Todd Pacific Shipyards and Atlantic Marine to incorporate DFP methodologies into the ship design process at each yard to enable simplification of the ship design process and vessel construction requirements. They sought to provide the U.S. shipbuilding industry with a reliable methodology to minimize excess design variations through the incorporation and delivery of a comprehensive DFP guide for vessel construction in mid-tiered shipyards. The core of the technical approach was centered around the development of shipyard DFP documentation, and publishing the information in a user-friendly format for easy reference in the design process.

During the first phase of the project, the team developed Structural Steel Preferences guidelines, which provide step-by-step process instructions to enable any U.S. shipyard to develop these preferences for their shipyard. The second and final phase of the project focused on the outfitting preferences for which a similar guidance document will be developed.

The final data was compiled in the form of easy-to-follow tables for key ship production focus areas which include: steel, piping, machinery, electrical, HVAC, joiner, paint and steel outfit. In addition, for each area, functional design rules, modeling design rules, and production design rules were derived to standardize the design requirements and processes for the project. With the design rules and processes standardized, the requirements could be stabilized yielding a more efficient design and build cycle. Lastly, an implementation pilot project will be performed in order to evaluate the revised ship design process using the DFP documentation as guidelines.

A complete DFP manual, with non-attributable shipyard data, and a template with instructions was created to aid other U.S. shipyards in developing their own DFP manuals.
**Benefits:** Project goals included a 10% reduction in structural part count and a 16% reduction in detailed design lead time.

**VCS Supply Chain Technology Review**

**Issue:**

Recent independent studies have concluded that Design for Production (DfP) is the single most influential factor to reduce ship production cycle time and costs, as ship design processes are not keeping pace with state-of-the-art manufacturing practices. The production work force must receive timely, accurate, configuration-managed, electronic data on-demand; meeting their information needs.

**Initiative:** To this end, this project evaluated existing construction data models and proposed new expanded 3D product model concepts for the VIRGINIA Class Submarine (VCS) program. The objective was to develop and implement a DfP “seamless deliverable” that supports manufacturing sequence workbooks.

It was understood that this expanded 3D model would have to include many more aspects of the design and construction data compared to the existing 3D model. Also, the work package would have to integrate design data with the planning and execution data so that all essential design elements could be captured and understood by shop floor personnel. Finally, for complex, lengthy, or especially unique work, manufacturing aids would depict construction sequence and other pertinent details obtained from separate product models and drawings.

This ManTech project first developed the structured relationship between work package data and manufacturing aid requirements, ultimately linking the textual design and engineering data with a 3D product model. The 3D model was then expanded to cover the full spectrum of information required to be depicted in the manufacturing aid to support the shop floor in order to eliminate textual data elements and 2D paper drawings. This will ultimately establish the expanded 3D product model as the single source for data access by all stakeholders.

The expanded 3D product model was completed in March 2009, when tradesmen successfully fabricated VCS structures using the developed pilot models. The results validated the use of the 3D models and their support of production work on VCS while eliminating duplicate efforts, improving configuration management, and ultimately reducing costs. It will be used as part of the shipyard’s DfP initiative, in conjunction with a new DfP knowledge management system and advanced visualization technology, intended to improve the process for design and fabrication of ships’ structures.

The full scale 3D Product Model has been partially implemented for use at Electric Boat’s Groton and Quonset Point facilities for VCS hull SSN-784, and results are being shared with Northrop Grumman Shipbuilding – Newport News. Technology transfer has been facilitated through numerous presentations regarding the plan, progress and results of this program.
Benefits:

Benefits to the warfighter include:

- Estimated cost savings per hull: $500K based on anticipated use rate.
- Significant improvement in pre-production processes
- Single source for production data.
- Reduced number of steps/time spent handling.

Open Architecture - Impacting Ship Acquisition Affordability

Issue: The current approach for conducting Navy affordability analysis is labor intensive, inconsistent and does not leverage the latest in desktop information technology (IT). For Navy analysts to create a ship system performance assessment framework, many months of manpower are required to create a series of Excel spreadsheets to identify performance requirements and link those requirements to desired threshold performance values. As different technologies are identified, analysts typically create additional tabs and manually document key performance attributes. In some cases, when modeling and simulation results are available, that data is not completely leveraged due to the limitations of an Excel-based infrastructure to incorporate multiple performance scenarios resulting from current simulation tools. As analysts leverage existing desktop tools within frameworks such as Microsoft Office, each analyst creates an infrastructure to apply to the current affordability question. Over the course of just one to two years, an analyst typically creates multiple frameworks, in each case re-developing a framework. Each organization creates similar infrastructure, but in each case implements different Office tools and “add-in’s” that result in slightly different approaches to attempt to provide additional insight into the trades that are impacting ship system affordability.

Another significant challenge regarding completing Navy affordability analysis relates to the ability to quantify development, production and operations and sustainment costs efficiently, early enough in the development life cycle to be able to modify the design to optimize cost. Traditional ship system life cycle cost processes rely on cost estimating relationships (CERs) that were appropriate for a certain contractor implementing a specific technology. Typically, the historical CERs are tailored as better production related data becomes available. However, by the time that data to tailor the CERs are available, the design of the ship system cannot easily be modified. Access to a family of cost models to provide robust insight into technology cost earlier in the life cycle is needed to enable early acquisition milestones to consider reasonable cost estimates.

Initiative: Technology for Shipbuilding Affordability (N05-039) is a Small Business Innovation Research (SBIR) topic which has an objective to develop and implement innovative technologies that will reduce the cost and cycle time to construct, modernize and repair Navy ships. The goal is to provide technology that will enable the shipbuilding community to have the tools necessary to assess and evaluate quickly the affordability of new systems, modifications or enhancements that are being considered at all phases of the ship system life cycle.
The initial research effort identified tools, data sources and an innovative methodology that enables affordability insights early in the Systems Engineering design process. Additionally, this effort demonstrated how Navy ship system data sources could be integrated with a structured desktop computer tool to provide both insight and traceability from requirements analysis through performance evaluation to Life Cycle Cost (LCC) estimation. This evaluation concept provides insight into the parameters affecting Navy system affordability. FTI’s Affordability Analysis Tool Suite consists of the Integrated Cost As an Independent Variable (ICAIVTM), Integrated Cost Estimation (ICE™) and Resource Optimization System (ROS) tools and associated affordability assessment methodology. They are complementary to those tools already in use and can contribute significantly to existing affordability assessment capabilities. These tools employ Department of Defense (DoD) community-accepted cost models, analysis tools, data, and processes that enable designers, analysts, engineers, planners, and decisionmakers to conduct cost and performance evaluations quickly and with little specialized training.

Data translators were also developed to interface with the Navy Collaborative Development Partnership (CDP). The CDP was initiated by PEO Ships and PEO IWS to implement open architecture data standards to enable the efficient sharing of new technology data. FTI is able to transfer life cycle cost information as well as cost versus performance summaries to a collaborative database called Open Architecture – Technology Transition Management Environment (OA-TIME). The exchange of technical and programmatic data in real time enables analysts to collaborate as new technologies are being evaluated for potential start up programs as well as back fits.

**Benefits:** The Affordability Tool Suite can be used to support ship system affordability analysis throughout the acquisition life cycle. From early concept exploration to the refinement of back fits and modifications, the affordability tools can be tailored to provide insight into cost drivers and ultimately, design-to-cost exercises. This analysis infrastructure can be applied to DDG 1000 Multi-mission Destroyer, CVN-78 Aircraft Carrier, Littoral Combat Ship (LCS) and the SSN 774 Virginia Class Submarine. In each of these examples, the Navy is trying to maximize the capability for the dollar invested in new technologies and systems. The Affordability Tool Suite provides a framework to address consistently the rising cost of ship system development and production by key performance and cost drivers to be identified and decomposed to objective and threshold levels early in the concept design phase.

The Navy Affordability infrastructure being developed can be used across Navy program offices as well as major prime contractors. The same basic infrastructure has already been adapted and used by several organizations outside the Navy, such as Missile Defense Agency (MDA) for portfolio analysis, the Army Aviation and Missile Research and Development Center (AMRDEC) for quantification of product assurance best value resolutions, and Air Force Space Command (AFSPC) Space and Missile Center (SMC) for the evaluation of multiple Global Positioning Satellite (GPS) system acquisition strategies and technical interface assessment analysis.

**Supply Chain Management**

**Issue:** Ship Acquisition Affordability is a primary strategic focus of the Navy Manufacturing Technology (ManTech) Program. The Navy ManTech program makes investments in
technologies that will have a beneficial and measurable impact on the materials, processes, or fabrication methodologies that will ultimately reduce the cost of ship construction and integration. No formal process or tool exists within General Dynamics (GD) Electric Boat Corporation (EB) Materials Management to enable their buyers to consistently identify and proactively manage Material Risk to support maintaining a 96% on-time material delivery attainment rate.

**Initiative:** The objective of this Benchmarking and Best Practices Center of Excellence (B2PCOE) project is to conduct benchmarking to support General Dynamics Electric Boat’s (GDEB’s) existing efforts to establish a formal Material Risk Management process to assure and maintain a viable industrial base for VIRGINIA Class submarines (VCS) by 2QCY11. Successful execution of this task will include identifying and piloting of a Material Risk Management tool. The benchmark activities will identify Material Risk Management processes and tools likely to support the risk facing GDEB for VIRGINIA Class submarine construction. The activities associated with this project include development of a benchmarking and implementation plan, creation of a Current State (―As Is‖) Process Map to baseline the existing informal Material Risk Management processes, benchmarking events and associated gap analyses, and identification of best-in-class Material Risk Management practices to support implementation.

**Benefits:** In addition to cost avoidance, anticipated cost savings is based on the following: (1) estimated reduction of 500 labor hrs per hull in the Service and Support Major Milestone (MM97) based on earlier conduct of risk identification and mitigation activities related to supplier viability, on-time material delivery, and material quality yields $42.5K savings per hull and (2) estimated reduction of 15 non-conformances per hull (i.e., Engineering Reports (ERs), non-conformance Vendor Information Requests (VIRs), and Supplier Corrective Action Reports (SCARs)) at a cost of $500 per non-conformance yields $7.5K per hull. These targeted benefits represent a cost savings opportunity of $50K per hull and have not been accounted for in the VIRGINIA Class Block III construction contract.

**Air Force**

**Leading Edge Supply Chain Study**

**Issue:** 21st century systems acquisition requires new generation of SCM practices.

**Initiative:** This study seeks to uncover the emerging trends in supply chain management (SCM) practices, processes and metrics that could be beneficial to the Department of Defense, with particular emphasis on the U.S. Air Force. This leading edge study of SCM will guide the Air Force in the future. It is anticipated that there will be immediate adoption of some findings by industry. This initiative also affords opportunities to pilot leading commercial practices in a defense setting.
The Produce Life Cycle Support Implementers’ Forum

Issue: Throughout the defense communities there are numerous products and weapons systems that were developed without the concept of data exchange through the entire life cycle of the product. The need to share information about the product life cycle occurs in many situations, from prime contractor to maintenance, repair and disposal vendors. Currently, there is no unified approach to address the issue.

Initiative:
The Produce Life Cycle Support Implementers’ Forum can help to solve these types of interoperability issues by use of the model-based Product Life Cycle Support standard (ISO 10303, commonly known as STEP).

LOnTerm Archiving and Retrieval Program (LOTAR)

Issue: Manufacturing data stored in proprietary formats becomes unusable within a few years, resulting in re-entry and data loss costs when equipment needs to be replaced or repaired.

Initiative: The LOnTerm Archiving and Retrieval program (LOTAR) is focused on the development of a model-based standard for archiving and retrieving product data, supporting tools, and recommended practices. LOTAR supports the ISO manufacturing standard for exchanging product data (ISO 10303, commonly known as STEP) functionality such as Cloud of points validation properties.

Customer Supplier Interoperability (CSI)

Issue: Lack of defined data exchange format requirements between suppliers and customers generate significant hidden costs for weapon systems. Supplier and customer data contract requirements vary and result in manual conversion processes and data loss during these conversions resulting in unnecessary costs. Inefficient technical data exchanges between suppliers and customers generate significant hidden costs for weapon systems.

Initiative: The CSI project will attack the problem of sharing product information during the collaborative phase of design. It will deal with contracts specifying different data requirements, including standards-based submittals and native-based submittals, and enable companies to support very complex requirements.

The CSI team will capture, validate and test “data-contract” requirements by assessing the requirements, evaluating the highest priority requirements and developing prototype solutions for the most critical requirements. Using the DEXcenter, ITI will develop CSI modules, to include contract mapping language tools, software libraries and other modules to address the requirements. A demonstration will be conducted to highlight the savings achieved through automation and a commercialization plan will be developed. This project will demonstrate cost and schedule savings by automating 3D data delivery. Every contract has unique data delivery requirements. Significant manual intervention is typically necessary to meet delivery requirements. The estimated DoD interoperability cost for 3D
Technical Data is $2B to $4B / year. Automating the processes required to prepare and deliver data can provide significant savings and ensure quicker and more accurate data delivery. Three primary collaboration/data exchange areas of interest are:

- Contract Deliverables (OEM -> Air Force)
- 1st Tier Supplier Design Collaboration/Contract Deliverable (OEM <-> 1st Tier Supplier)
  - Design Integration (3D geometry for collision detection, installation dataset creation, design reviews)
  - TDP deliverable per SDRL requirements
- Build To Print Data Exchange (OEM -> 1st Tier Supplier)

The program differences entail the following:

- Heritage programs (F16, C130, F22) – “Traditional” TDP deliverable requirement based on Mil-STD-31000
- F35 – TDP deliverable accomplished through single point of entry data access to customer
- Supplier TDP requirements still similar on F35 but Design Integration tasks delineated in SDRL (prefer OEM’s native CAD format)

The level of effort to support the scenarios are not heavily automated. SDRL terms are not consistent. Special agreements are in place for GFE suppliers (e.g., Propulsion team). Common strategies and contract terms are being sought to ensure consistent data formats and processes that streamline operations and IT investments.

The following outline shows the steps that will be taken:

Task 1 – Assess delivery requirements
Task 2 – Estimate costs and prioritize areas to address
Task 3 - Prototype and demonstrate automation elements

In Task 1, the team will review actual contracts and identify required provisions, capture routine practices, incorporate combined experience and knowledge of the team, conduct interviews and surveys as appropriate, leverage NIST MBE TDP / DoD Engineering Drawing & Modeling Working Group, and perform a GAP analysis of existing versus needed capabilities. Identified GAPS will be prioritized based upon greatest potential savings / schedule impact:

- Estimated costs of fulfilling these requirements with current manual or other methods
- Estimated benefits to be received through automation.
In Task 2, when estimating costs and prioritizing areas to address, the following will be evaluated:

- Areas affecting costs
  - Direct costs
    - Time to perform the various model preparation tasks
    - Infrastructure and resources needed to facilitate model preparation and delivery tasks
    - Training of personnel
  - Consequential cost
    - Project delays
    - Project failures / recalls
    - Lost opportunity (designers could be improving product)
- Actual costs if known
  - Outsourced
  - Centralized translation support
  - Other tracking
- Estimates
  - Based upon actual experiences of personnel making the changes

Task 3 involves prototyping automation elements for highest priority items. This will require development and analysis of requirements for each GAP item. Prototype automation elements to address the highest priority items will be built upon existing ITI capabilities

- DEXcenter
- PDElib
- CADscript

Key to this initiative will be to identify the time and cost savings for the automated requirements. Time and cost data associated with using the prototype automation elements will be compared to actual time and cost data to identify schedule and cost savings. A demonstration on automation and how it impacts cost will then be conducted.

It is envisioned that this will culminate in a flexible, configurable, standards-based system which automates common tasks associated with Customer Supplier Interoperability.

**Benefits:** The warfighter will benefit from the results of the customer supplier interoperability project due to reduced costs and higher quality data. Improvements in business practices will be seen in:

- Less cost to deliver products to the warfighter by eliminating non-value added data manipulation tasks and elimination in errors introduced in the manual manipulation of the data
- Less time for new capabilities to reach the warfighter because of streamlined processes through the supply chain during early product development phases
Annual costs savings are estimated to be over $35 million per major program.

Rapid Enterprise Advanced Laser Modeling (REALM)

**Issue:** The Department of Defense (DoD) has been increasingly impacted by a diminishing base of parts suppliers caused by a combination of aging weapons systems with extended life cycles, reduced manufacturing capacity, disappearing Original Equipment Manufacturers (OEMs) and missing or incomplete technical data.

**Initiative:** This initiative involves performing a top-level assessment of the “as-is” laser scanning capabilities at each of the three Air Logistics Centers (ALCs). Through this, the following will be defined:

- a set of functional scanning-based reverse engineering capabilities, processes, and attributes common across ALCs
- specifications for a common interface for scanned data and 3D modeling capability with most commonly used CAD systems
- a top-level architecture for a reverse engineering data exchange enterprise that integrates all three ALCs.

Individual site surveys will be performed at three Air Force Logistics Centers (AFRLs). These include WR-ALC Robins AFB, OC-ALC Tinker AFB, and OO-ALC Hill AFB. A comprehensive survey plan and checklist will be developed to assess and document the extent of laser scanning currently performed at each of the three centers for reverse engineering and quality assurance purposes to include systems and processes.

An analysis of the data gathered at the ALCs will be conducted in order to define:

- A set of functional scanning-based reverse engineering and quality assurance capabilities, processes, and attributes that may be common across all of the ALCs, regardless of the physical resources used.
- The specifications for a common interface that permits cloud of point data from the major laser scanning systems to interchange with the 3D modeling capabilities that are basic to the most commonly used CAD systems.
- A top-level architecture for a reverse engineering data exchange enterprise that integrates all (3) ALCs (and AFRL if applicable/desirable) via creation, use, and management of laser scanning-derived 3D CAD models.

A Standardized Process Model will then be developed along with a Validation Plan, based on the recommendations from the requirements analysis that will identify the key players, establish clear objectives and direct the execution of the validation. The validation will collect metric data that provides empirical results. Analysis of the metric data will refine the Standardized Process Model. Validation will confirm that the requirements of the Standardized Process Model conform to the user needs and specifications.
A Demonstration will then be held to show the practicality and feasibility of establishing an enterprise-wide, scanning-enabled, reverse engineering environment across the ALCs. The demonstration is planned to be a three-day event and to be held at one of the ALCs or in the ATI lab. Two parts from the ALCs will be selected to be used in the demonstration and perform the reverse engineering tasks and the quality assurance tasks to exercise the entire process. The recommended solution set will be implemented and exercised using equipment through the cooperation of the ALCs and/or through special vendor arrangements.

The objective of Phase II is to fully integrate the core hardware, software and process components at one or more ALC sites to equip them with the optimal solution. The technical approach to be conducted under this phase will ensure the components that compose the final solution can be integrated with the unique processes and technologies at each ALC while adhering to the site-neutral model. This phase will leverage the research from Phase I to acquire the core components necessary to augment the technologies in use at the ALCs such that the final solution can be achieved for each.

**Benefits:** The benefits from this initiative are the provision of a Technical Data Package (TDP) development solution that is embedded in legacy processes to reduce costs. This will allow for optimization of the process using “as-is” reverse engineering processes. A reduction in cycle time will be achieved from reverse engineering to 3D model to supplier-base:

- Reduce manufacturing time through use of model-based manufacturing.
- Increase quality assurance capabilities and reduce cycle time.
- Reduces DoD investment through technology re-use.
- Increase the ALC supplier-base (organic, commercial).

**Missile Defense Agency (MDA)**

**Supply Chain Initiatives**

**Issue:** Commercial and defense manufacturers are required to transition proven designs to manufactured product in a manner which achieves affordable production within increasingly reduced lead times. Further, more products must be manufactured to exacting quality standards to satisfy extremely high demands for mission success. Office streamlining should be conducted in parallel to meet engineering and manufacturing competitive demands.

**Initiative:** DRC’s Continuous Improvement (CI) approach provides a unique transformation process to drive enterprise-wide improvements (waste elimination, cycle time and quality improvement, and cost reduction) at small and medium-sized suppliers, at a division of a major corporation, and with defense activities. To date, DRC has engaged five prime contractors, 47 supplier companies at enterprise level, one Air Force Logistics Center and five Navy Aircraft Carriers (Lean Engagements in Critical Areas and Lean Leader Certification). CI supports improved value chain performance and weapon system affordability and availability. The CI tools—Lean, Lean/Six Sigma-Pathways®, Six Sigma and Theory of Constraints—provide company senior management leadership teams with a proven, common sense metrics approach that transforms their organizations, not just to CI thinking, but all the way to
successful, results-oriented enterprise transformation (implementation/sustainment). The CI tools can be used internally and/or with the supply chain or supply centers and maintenance activities. CI is based on the Lean and Lean/Six Sigma-Pathways process, enhanced with applicable Six Sigma and Theory of Constraint tool sets and processes, as the situation and DoD/product requirements dictate. It also supports the tenets of the newly issued DoD Continuous Performance Improvement Guide and policy. Consequently, end users are provided with the industry practices in Continuous Improvement which is applied with a metrics approach. The solution includes the joint development of a strategy which addresses the planning, programming and execution of the CI process. This includes a macro-value stream analysis of each element of the Enterprise, which combined with the customer and supporting industrial contractor inputs, identifies critical opportunities for CI and the priority order in which they are addressed.

Executive and tactical training requirements are defined based on a Lead, Mentor, Support philosophy so that the Enterprise becomes fully capable in all aspects of the transformation process to eventually assume their roles as internal change leaders and facilitators. The entire training process is complemented with an extensive certification process based on industry recognized (such as the American Society for Quality) Green Belt, Black Belt, Master Black Belt and Train the Trainer standards.

**Benefits:**

With 47 suppliers and five aircraft carriers on Lean-Pathways/LSS programs, the following benefits may be realized:

- 30% to 50% reduction in cycle time
- 10% to 25% quality improvement
- 10% to 30% waste reduction
- 10% to 25% inventory reduction
- 10% to 48% cost reduction
- Much closer alignment with customers and customer metrics.

**Defense Logistics Agency (DLA)**

**Technical Data Package (TDP) Intelligent Specification Assistant (ISA) for Government Contracting**

**Issue:** Each Service and program office uses different logic to establish the range and depth of information in TDPs acquired to support weapon systems. There are different levels and classes of data that can be extremely ambiguous and difficult for the Government to specify in an efficient and optimal manner. Currently, DoD does not have a tool to help determine the proper level and content of TDPs that are required.

**Initiative:** This project involves actively engaging with the Services’ Program Managers (PMs) and Program Executive Officers (PEOs) to determine how to provide strategic support throughout logistics life cycle management. The goal is to develop an ISA tool to guide the
project/product manager through the contract process that will result in tailored and integrated statements of work (SOWs) and Contract Data Requirement Lists (CDRLs) for TDP requirements. It involves incorporating specific TDP contracting requirements based on needs identified through the Contracting for Technical Data Packages effort. The project includes the following steps:

- Develop requirements for ISA tool for TDP as it relates to contracting, current industry standards, and military specifications.
- Assist the Navy in their effort to incorporate and improve the Engineering Data for Provisioning and Logistics Product Data capability in SMART-T. Modifications to be based on new industry standards and military specifications.
- Assist the Army in their effort to develop an engineering module for SYSPARS based on new industry standards and military specifications.
- Develop and test ISA tool based on requirements and recommendations resulting from analysis and best practices from SYSPARS and SMART-T IT systems.
- Provide ISA tool to appropriate Services and departments performing contracting for TDP and training activities.

The ISA tool is an IT system as defined in 44 U.S.C. 3501 (8). It will result in providing the right balance of technical data to support the individual programs’ unique requirements for TDP with a standardized and cost effective method. The ISA tool will expand upon and incorporate enhancements made to the Navy’s Streamlined Modular Acquisition Requirements Tailoring Tool (SMART-T) and the Army’s Systems Planning and Requirements Software (SYSPARS). This tool will be delivered to the applicable offices within the Military Services, Agency HQ’s, and OSD. It will be provided to the Department of Defense Engineering Drawing and Modeling Working Group (DEDMWG) SharePoint site. In addition, the ISA tool will be published on the DAU website for contracting and contract training purposes. Enhancements to SMART-T will be part of the established SMART-T system and will be implemented via their website. Enhancements made to the SYSPARS system will be implemented via their website.

**Benefits:** The outcome of this initiative is an ISA tool that will be available across DoD. The tool will aid program offices and program managers in acquiring complete TDPs necessary for life-cycle sustainment of systems. The Navy and Army will benefit from this effort through enhancements to their acquisition/planning systems.

**Technical Data Packages within Model Base Enterprise**

**Issue:** Weapons systems development is moving towards a concept called the “Model Based Enterprise (MBE).” The MBE links model-based engineering, manufacturing and sustainability. Acquisition tools and techniques for TDP are still largely based in the paper document era, and have not caught up with the MBE concept. This results in insufficient data or missing data in the Federal Logistics Information System (FLIS) that drive up life cycle costs.

**Initiative:** The purpose of this project is to actively engage with the Services’ Program Managers (PMs) and Program Executive Officers (PEOs) to determine how to provide strategic
support throughout logistics life cycle. This project baselines current TDP acquisition practices as they are applied to the MBE environment. The technical approach entails the following:

- Identify and poll a representative sample population of TDP users to define the full range of TDP requirements.
- Compile a representative list of current and legacy contracts, and examine TDP SOWs, DIDs, and CDRls for trends and standard practices.
- Research a Service and Agency cross section of program offices to identify and document the knowledge level and expertise of each office in the MBE TDP environment.
- Create a reference portfolio of documents and language for MBE TDP deliverables.
- Write a BCA.

The baseline will highlight insufficient or missing data which arise from the use of obsolete contract data requirements lists (CDRLs), statements of work (SOWs) for TDP acquisition, data item descriptions (DIDs), and similar document specifications. This project will also create a reference portfolio of documents and language for MBE TDP deliverables and a business case analysis (BCA). This project does not involve IT development.

The reference portfolio and BCA will be sent to the applicable offices within the Military Services and Agency HQs, as well as OSD, with the recommendations to change and implement policy or develop training to ensure identified best practices are fully understood and utilized by PMs and PEOs.

The Defense Acquisition University’s (DAU) Defense Acquisition Portal will also be used to communicate with the user community.

**Benefits:** This project will help move the DoD acquisition community forward into the MBE environment, specifically in the area of TDP acquisition.

**Related Work:** "Contracting for Technical Data Packages (TDP) within the Model Based Enterprise" is one of three R&D projects being simultaneously developed by DLIS. The other two projects are "Technical Data Exchange Pilot within the Model Based Enterprise" and "Technical Data Package Intelligent Specification Assistant". These efforts are synergistically tackling the need to baseline current practices, develop data exchange requirements, and develop training tools – all necessary for keeping pace with the weapon system shift to model-based engineering.

**Tech Quality Tool Set (TQTS)**

**Issue:** Incomplete and inadequate part information causes longer lead-times, increases materiel costs, raises the risk of paying unreasonable prices, and increases the DLA workload needed to manage Class IX items for warfighter support. This project will establish a capability to rapidly harvest and update Federal catalogue data from hundreds of supplier websites including: price, stock on hand, item technical characteristics, and engineering drawing/models (if available).
**Initiative:** This initiative entails designing and developing a DLA retail strategy to optimize related supply chain performance factors for DLA Commercial Class IX items stocked and described on hundreds of web based catalogs. This project will:

- Provide standardized part characteristic data to stakeholders based on Government and commercial item taxonomies
- Develop Application Program Interfaces (API) that could enable DRMS and DLIS systems to quickly and easily incorporate item data
- Improve the interactive, graphical user interface used to access data
- Develop testing, validation and data quality systems to ensure continuous quality output
- Collect data to evaluate the effectiveness of Software as a Service (SaaS) approach to providing data to DLA interactive Tech/Quality, and Acquisition users.

Transition planning will be conducted as a joint effort among the R&D team and the T/Q Process team, and J-6. The J-3314 Process Owner will be the primary initial decision authority for any deployment and/or impact to business processes/policy issues.

**Benefits:** Anticipated benefits will include: reduced lead-times resulting from identifying additional sources for “no-bids” and for items flagged during Product Quality Deficiency Reports (PQDR) review; lower materiel costs through increased standardization of parts identification data and increased competition; lower probability of unreasonably priced items; and reduced warehouse space requirements by relying on commercial inventory to augment/replace Government inventory.

**Related Work:** Several DORRA-sponsored proof-of-concept projects were developed under the Defense Logistics Information Research Program. These pilots:

- Acquired, extracted, and standardized attributes for approximately 500 K NSNs
- Identified NSNs stocked by DLA with five or more commercial sources of supply with 24-hour delivery. The rough order of magnitude benefits were estimated to be a five to ten-fold reduction in lead-time and a $30 M reduction in working capital invested in stock
- Quantified commercial stock on hand, availability and lead-time from many vendors
- Provided links to images, Material Safety Data Sheets (MSDS), regulatory data for Restriction of Hazardous Substances (RoHS), Registration, Evaluation, and Authorization of Chemicals (REACH), Lead Free, Computer Aided Design files, and other physical attributes.

**Automate 'Reading' of Text on 2-D Drawings; Convert 2-D to 3-D Solid Models**

**Issue:** Several DOD suppliers do not respond to bids for solicitations of parts for legacy weapon systems claiming that the TDPs contains raster drawings, which are often unreadable or the part drawing is not easily interpreted. They say that the considerable pre-sales expense does not justify recreating the part in 3D to understand the cost because purchase volumes are low. In addition, DOD suppliers assert that they incur re-work and scrap cost due to the fact that the TDP
has missing information or that the drawing is misinterpreted, leading to revised quotes and added cost.

**Initiative:** This initiative entails utilizing shape search and 2D to 3D application technology to semi-automatically convert raster drawings contained in TDP to 3D models, enabling suppliers to leverage the 3D models to quote or incorporate into their 3D CAD environment

**Benefits:** The warfighter will reap the benefits of this initiative through the reduction of per unit procurement cost. An average of 27% cost savings per discrete part is achieved. This is due in part to the fact that higher supplier productivity leads to faster pre- and post-award turnaround times. Also, there are higher RFQ responses from suppliers due to the better quality of data that is provided. In addition, a reduction in the amount of scrap and rework is achieved since almost 19% of suppliers scrap (average $27,000) and re-work was due to poor raster drawing quality.

**DLA Technical Exchange Pilot within MBE**

**Issue:** DLA is falling behind as DLA external customers are developing new technology and adopting standards such as Government Electronics Information Association (GEIA) industry standard GEIA-STD-0007, supporting the 3D Model Based Definition. To an ever-increasing extent, Logistics Product Data (LPD) are embedded in engineering, process and sustainment models created by weapon system prime contractors in accordance with GEIA-STD-0007. When DLA and DLIS cannot accept data in the new standard for provisioning and procurement activities, DLA customers are incurring additional project costs. Those additional project costs generally include providing 2D engineering drawings and expensive manual data transfer methods. The Defense Logistics Information Service (DLIS) needs to develop methods to economically and quickly collect LPD in the GEIA-STD-0007 format so that it can be processed and disseminated by the Federal Logistics Information System (FLIS).

**Initiative:** This project will determine requirements for future research and development. Two pilots will be conducted – one will receive data from the Air Force A-10 Wing Replace Program and the other will receive data from the Oshkosh Mine Resistant Ambush Protected (MRAP) program. Systemic data exchange template will be established in the GEIA-STD-0007 Handbook to transmit LPD and engineering data. The data exchange for the A10 WRP will come from Boeing produced 3D development models. The MRAP data exchange will come from the 3D development models from Oshkosh. The characteristics structure inside the 3D developmental models for the A10 WRP and MRAP weapon systems will be developed. This initiative will also entail working in coordination with the weapon contractors Boeing and Oshkosk to standardize the metadata character schema through the use of the GEIA-STD-0007 standard. The tools and results will be published through the DoD Engineering Drawing Modeling and Working Group (DEDMWG) SharePoint site.

**Benefits:** A roadmap of future R&D requirements will be created to allow DLA to move towards the GEIA environment effectively.