Modeling & Simulation for Affordable Manufacturing

Technology Roadmapping Workshop

Workshop Preread Package

10 May 2002

Co-sponsored by the Air Force Research Laboratory and the National Science Foundation

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1.0 Call to the Workshop

1.1 Scope and Mission

The Air Force Research Laboratory (AFRL) Materials and Manufacturing Directorate and the National Science Foundation (NSF) are co-sponsoring a workshop on "Modeling & Simulation for Affordable Manufacturing." The goal is to define and document a common vision for the development and application of modeling and simulation (M&S) tools for radical reform of the manufacturing phase of the product acquisition cycle. The workshop will develop a plan to achieve the vision, and incorporate this input into a technology roadmap. The roadmap will define the current state of M&S application in this area, the vision for the future, and a migration strategy to realize the vision.

The workshop will be held May 20-23 at Lake Buena Vista, Florida at the Sheraton Safari Hotel. The activities will begin at 6 p.m. on Monday, May 20 with a dinner and an introduction to the workshop goals and methodology. The workshop will adjourn at noon on Thursday, May 23 in time for afternoon flights. Further information on meeting logistics is provided in Appendix A.

The workshop participants represent a broad cross-section of knowledge in the development and application of M&S in design and manufacturing. While the major thrust of the activity is for the aerospace and aeronautics sectors, the challenges and solutions are common across many sectors. Therefore, the participants include representatives of the automotive, electronics, consumer products, chemical, process industries and other sectors; leading representatives of the M&S academic community also will participate.

The workshop will address goals of M&S for design and manufacturing. This scope includes the process of product creation, from concept definition through design and manufacture. The major emphasis of the workshop is on exploitation of M&S technologies to accelerate the pace and accuracy of the design process, thereby yielding products that can be produced at a lower life-cycle cost.

Figure 1 indicates the scope of the workshop within the context of the product life cycle. The major emphasis of the workshop is inside the circle of Figure 1 – on the product realization phases (i.e., design and

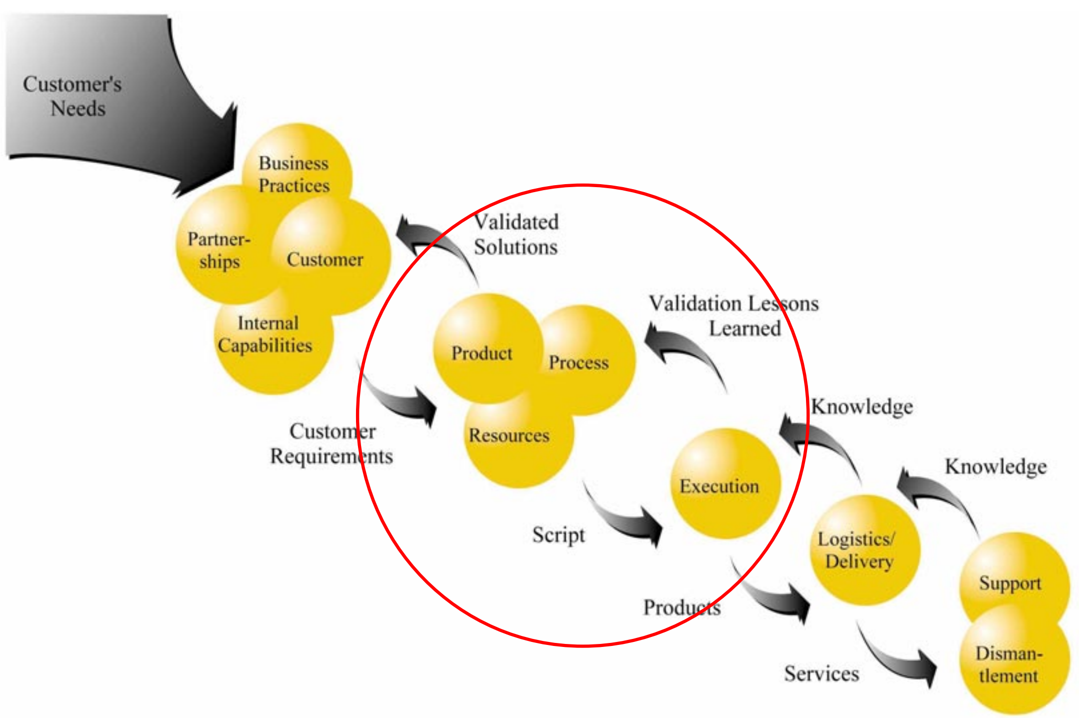

Figure 1. Design and manufacturing are closely interrelated elements of the product life cycle.

manufacturing) of the product life cycle. We show the total cycle here to illustrated the connectivity and dependency of all phases.

The DoD has invested heavily in M&S over the past few years to reduce the time and cost of developing and deploying new weapon systems. The corollary objective is to assure that the systems fielded are optimized for cost-effectiveness and for ability to perform their intended mission – both in their own mission context and as part of the overall "system of systems" that all must work together in the military theater of operations.

1.2 Workshop Preparation

The workshop will be two and a half days of intensive facilitated brainstorming and structured discussion. All participants are encouraged to arrive ready to work and committed to making the team process a success. Dress code is business casual.

IMTI will provide the facilitation services for the workshop and roadmap preparation; the workshop participants will deliver the content for the roadmap and assure that the content is faithfully represented in all deliverable documents. Since one goal of the workshop and the roadmap is to provide an accurate snapshot of the current state of M&S technology and applications, we ask you to come prepared with examples, facts, and figures. If your organization has a success story or a best practice or a specific technology barrier to share with the group, please bring it with you on disk to the workshop. You can also send any background material in advance to Doug Marks at dmarks1@cfl.rr.com.

We also ask that you read this package thoroughly to get acquainted with the workshop methodology (Section 3), functional model (Section 4), and the *Relevant R&D Abstracts* document provided separately with this preread package.

1.3 About IMTI

The Integrated Manufacturing Technology Initiative (IMTI, Inc.) is a non-profit organization dedicated to facilitating cooperative research and development that attacks the technology challenges facing U.S. manufacturing organizations. IMTI was formed by agreement of five government agencies (DoD, DOE, NSF, NASA, and DOC) and several leading corporations with the mindset that a neutral broker is needed to systematically support the nation's manufacturing infrastructure. IMTI has developed a robust process for creating comprehensive technology roadmaps based on a structured methodology (see Section 3), and is experienced in facilitation of strategic planning for manufacturing and technology-based organizations.

IMTI has published seven technology roadmaps that are available for download on the IMTI website (www.imti21.org). We encourage you to download and read the *IMTI Roadmap for Modeling & Simulation*. Published in July 2000, the M&S roadmap provides a comprehensive view of M&S technology needs for future manufacturing enterprises. The M&S roadmap was developed and reviewed by a diverse team including representatives from industry, government, and academia:.

- Bechtel Corp.
- Caterpillar Corp.
- Chrysler Corp.
- Defense Advanced Research Projects Agency
- Delmia Corp.
- Institute for Defense Analysis
- Intel Corp.
- Johnson Controls
- Knowledge-Based Systems, Inc.
- Lockheed Martin Corp.
- MacNeal-Schwendler Corp.
- National Center for Manufacturing Sciences
- National Institute of Standards & Technology
- National Science Foundation
- Oak Ridge Centers for Manufacturing Technology
- Penn State University
- Procter & Gamble
- Rennselaer Polytechnic Institute
- Rockwell Collins
- Sandia National Laboratories
- SAP Labs, Inc.
- Structural Dynamics Research Corp.
- Tinker AFB
- U.S. Department of Energy

2.0 BACKGROUND

2.1 Business Drivers for Improved Modeling & Simulation

Despite significant progress in recent years, defense acquisition span times remain far too long to support a responsive defense community that must react quickly to changing global missions and technology advances. This increases the danger of fielding outdated technologies, inflates development costs, and jeopardizes implementation milestones. Design changes throughout the development cycle to respond to revised performance requirements or budgets are common, further increasing development cost and time.

DoD has made significant investments in M&S under the aegis of the DoD Modeling & Simulation Master Plan (DoD 5000.59-P) and initiatives such as Simulation Based Acquisition (SBA). However, the focus of these efforts has primarily been on synthetic environments, simulation architectures such as HLA (High Level Architecture), and simulation to support wargaming, operations analysis, and training. Such tools are vital to developing and refining requirements as an input to the acquisition process, aiding in understanding the relationship of needs and costs across the entire life-cycle of the weapon system. However, excluding high-visibility programs such as Joint Strike Fighter, focus on the design and manufacturing aspects of the acquisition process has been inadequate to drive radical improvements.

The DoD M&S Master Plan does address a broad vision for exploitation of M&S in system development (Figure 2) ; however, this vision does not extend much beyond the identification of virtual prototyping and virtual field-testing as tools for streamlining the development process.

Better integration of the design and manufacturing phases is widely accepted to be a key driver of reducing time from concept to delivery. The disciplines of concurrent engineering and integrated product/process development (IPPD) have made great strides towards integrating producibility and other manufacturing concerns in the design process. However, for major system acquisitions the gap between completion of Concept Definition and delivery of the first production unit remains one measured in years. Also, despite better integration of the design and manufacturing domains, a "final" production configuration still undergoes numerous changes after delivery of the first unit. This greatly complicates operation and maintenance (O&M), since training, maintenance, repair, and logistics supply must support each production variation.

Modeling and simulation is the key to optimizing the total product and system design before production; for optimizing the design for speed, quality, and affordability in production; and for optimizing the production processes so that they are in place and ready to execute upon production go-ahead. Maturation of the enabling technologies will enable system developers to slash months and years of development time, and reduce costs by 50% or better from current design/build/test/fix practices.

What M&S brings is the ability to iteratively evaluate, test, and validate product and process designs in the virtual realm. This will radically reduce the number of formal design changes that must be implemented in the development process. AFRL reports that one recent weapon system program had 90,000 engineering drawing revisions at an average cost of $16,980 per revision – a total of more than $1.5 billion because the design process couldn't "get it right the first time." [1]

A certain percentage of design change is unavoidable – requirements do evolve over time in response to external factors. Budget changes may dictate redesign to fit reduced funding profiles; revised threat/competitive assessments may dictate higher performance; or a newly emerging technology may offer improvements in cost or capability that warrant inclusion. However, M&S will not only enable designers to minimize unnecessary changes, it will enable them to respond quickly to desired changes, thus reducing impact on acquisition time and cost.

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[1] *Integrated Manufacturing Simulation for Affordability, A White Paper*, AFRL, March 2001.

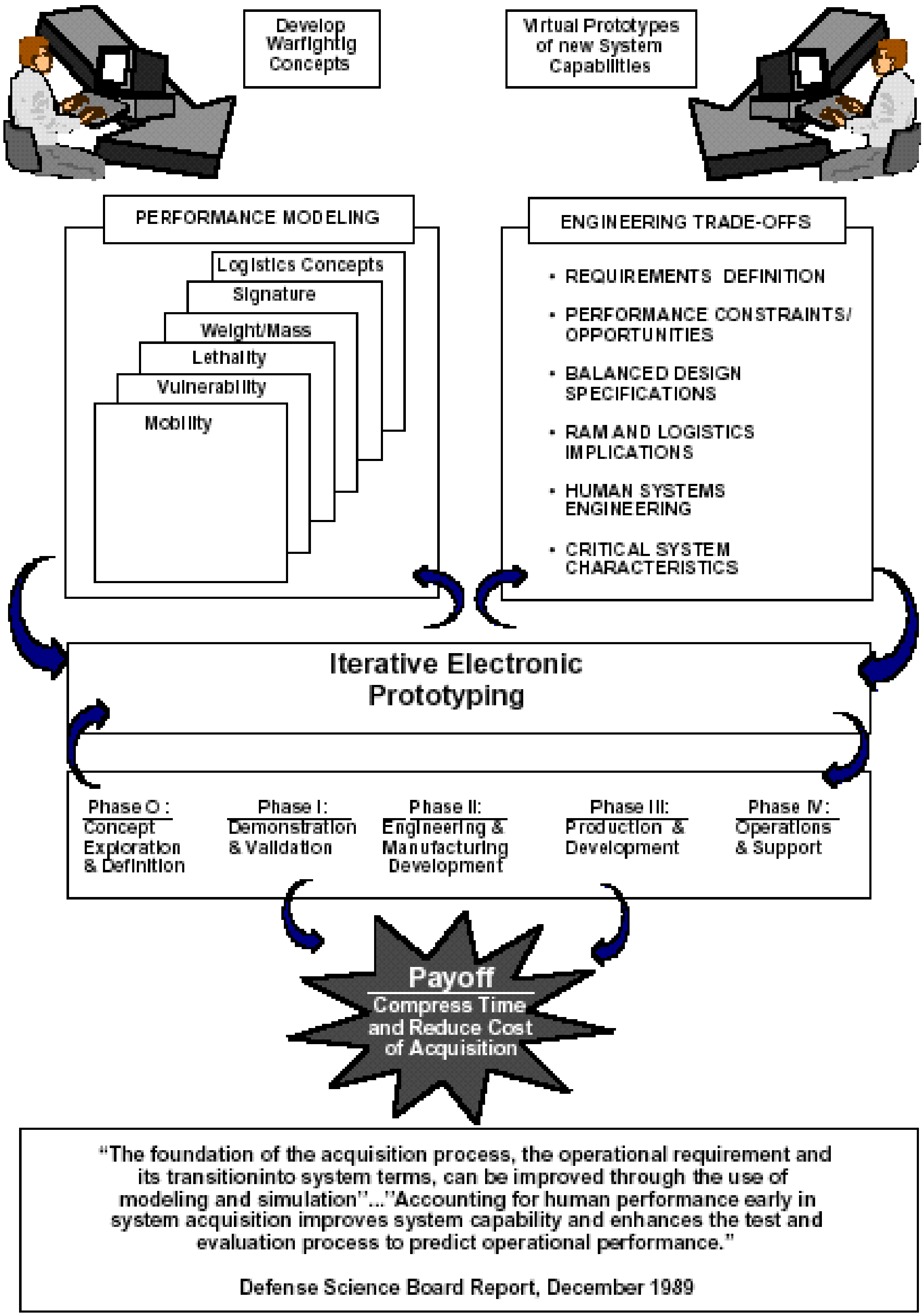

Figure 2. Vision of M&S Support to the Acquisition Process
(from the DoD Modeling & Simulation Master Plan, DoD 5000.59-P)

2.2 Technology Challenges

While the benefits of improved M&S may be difficult to quantify, there is no disagreement that the potential for benefit is profound. All of the technology-focused federal agencies are pursuing major initiatives in the form of studies and R&D programs. Table 1 identifies a few of the notable activities as of March 2001.

Table 1. Major Federal Initiatives in M&S

Program	Agency
Advanced Engineering Environments	National Research Council
Defense Manufacturing in 2010 and Beyond	National Research Council
Engineering of Complex Systems (ECS)	Office of Naval Research
Engineering Research Center for Computational Field Simulation	NSF
High Level Architecture (HLA) for Distributed Simulation	DoD
Intelligent Synthesis Environment (ISE)	NASA
MISSION	NIST
Simulation Assessment Validation Environment (SAVE)	USAF
Simulation Based Acquisition (SBA)	DoD
Simulation Based Design (SBD)	DARPA
Systems Integration for Manufacturing Applications (SIMA)	NIST

Although much has been accomplished in the development and application of M&S, there is still much to do. M&S applications have revolutionized product design over the last two decades; integration of applications into design "systems" has streamlined the design-to-manufacturing process. Manufacturing process simulation is providing the ability to make better decisions from a wider range of options. However, process simulation is focused on a case-specific basis with simulation tools tailored to high-need areas. As a result, there remain significant gaps in M&S technology – particularly in the provision of a general toolset that can be integrated across diverse manufacturing processes. The tools have matured and examples of impact have become more prevalent, but the ultimate success – the pervasive application of M&S tools to greatly reduce life-cycle product cost – is yet to be realized.

M&S must become THE method for product and process design. This requires both technological and cultural change. M&S tools are too often the domain of experts whose work is parallel to the product development effort. To integrate into the critical path, M&S must be used by the design team as an extension and support normal activities. The results must be presented in forms that can be understood and applied, without waiting for analysis and expert interpretation. The systems must be on-line as part of the design process and results must be timely. These technological capabilities will enable a shift in the design and manufacturing culture to the routine use of a rich suite of M&S tools to optimize designs quickly for performance, cost, and manufacturability.

In March 2000, AFRL convened a Technology Blue Ribbon Panel (TBRP) to address issues and challenges related to M&S for manufacturing in the defense community. The TBRP effort conducted an extensive research of published studies and conference and workshop proceedings to identify manufacturing M&S technology voids and barriers to implementation. In addition, the team conducted several one-day visits to various prime contractors, government organizations, and software vendors to identify and validate technology voids and gain insight into each company's needs and current information technology modernization plans. At a high level, the TBRP identified five technology voids it considered critical:

1. Physical representation
2. New and improved tools
3. Database integration
4. Ease of use
5. Training.

The Barriers

Although there has been a significant increase in the capabilities of commercially available M&S tools over the past several years, there are still many holes. The amount of time it takes to develop models and run simulations is too large to allow widespread use of the technology. Improvements in terms of rapid modeling, model modification, and analysis preparation can go a long way toward simplifying their use. In addition, the use of feature-driven designs and knowledge bases can significantly decrease modeling time. Tools that support multifunction optimization, process planning as a by-product of the development, and real-time cost as an independent variable are either immature or nonexistent.

The development and maintenance of databases and knowledge bases for design is a challenging and significant investment for any company or industry sector. A knowledge base that includes design allowables, reliability, producibility, cost, and other essential information is critical to achieving significant reductions in design time and for accelerating the development and insertion of new materials and manufacturing processes into the future product realization process.

Another key problem with the current M&S state of the art is the lack of tool and data integration. Some vendors do provide a monolithic integration approach for their own tool suite; however, this does not support individual tool selection and is certainly not “open” in any sense. By developing and applying open standards to appropriate design and analysis data, the M&S vendor community can provide a more flexible environment that will support best-in-class tools, legacy data and ultimately lead to widespread use of the technology. Many companies are investing heavily in master model systems to integrate databases across all aspects of their business. Integration of product engineering information is a high priority, but the larger strategy is to facilitate the transfer of information and data digitally among all enterprise functions. Integration of engineering, manufacturing, product support, and maintenance and repair knowledge will enhance the early design process and dramatically reduce the amount of design changes, quality problems, and time associated with fielding a new system. Master model systems that integrate CAD, CAE, and visualization tools with predictive models are being developed, with links to management functions, document management functions, and enterprise resource management (ERM) systems. These investments, while providing limited solutions for an internal architecture, will be difficult to implement across the extended base of suppliers and subsystem integrators, especially given the trends of increased outsourcing of engineering, manufacturing, and product support functions.

Design and manufacturing M&S tools available today tend to be training intensive and require experts to use them. Employing immersive environments and desktop visualization techniques along with a rapid modeling capability will significantly improve their usability. With these improvements, the training process becomes less cumbersome and reduces or eliminates the requirement for M&S experts.

A report currently being developed by Antoinette Maniatty of Rensselaer Polytechnic Institute (RPI) provides an excellent overview of current barriers to improved M&S capabilities for design and manufacturing. Briefly summarized, these are:

- Inadequate simulation capabilities (fidelity of simulation codes and ability to simulate complex phenomena)
- Difficult of use (expert knowledge needed for performing simulations)
- Lack of simulation synthesis (inability to integrate multiple codes, or integrate designs into the simulation environment)
- High cost of developing tailored simulation capabilities
- Ability to accommodate uncertainty
- Psychological and sociological barriers (acceptance of M&S tools as mainstream to the development process)

3.0 WORKSHOP AGENDA AND METHODOLOGY

3.1 Workshop Agenda

Monday, 20 May

6:00 p.m.	Dinner and Welcome at Sheraton Safari Hotel
6:45	Overview & Discussion of Workshop Process
8:00	Adjourn

Tuesday, 21 May

7:30 a.m.	Continental Breakfast
8:00	Plenary Session: M&S Perspectives
9:30	Functional Model Discussion
10:00	*Breakout Session 1:* **Current State Assessment**
Noon	Lunch – Brief report from each group on progress
1:00	Return to Breakout Session 1
2:00	*Breakout Session 2:* **The Vision**
5:30	Adjourn

Wednesday, 22 May

7:30 a.m.	Continental Breakfast and Team Progress Reports
8:30	*Breakout Session 3:* **Goals and Requirements**
Noon	Lunch
1:00	Completion of Goals, Requirements, & Timeframes
3:30	Identification of Critical Capabilities (Top 10 for each Group)
4:30	Presentation of Critical Capabilities
5:30	Adjourn

Thursday, 23 May

7:30 a.m.	Continental Breakfast and Prioritization of Critical Capabilities
9:00	Group Discussions: Action Imperatives
9:30	*Breakout Session 4*: Action Imperatives and Next Steps
11:30	Group Report-out
Noon	Adjourn

3.2 Workshop Methodology

The conduct of the workshop and the organization of the roadmap will be based on a functional model that defines the areas of emphasis for M&S. A draft of that model for consideration and consensus is shown in Figure 3 below. Definitions for each of the model's elements are provided on the following page.

The workshop will be a combination of large and small group activities. Four breakout groups will address the respective top-level "elements" of the functional model:

1. Product Design and Optimization
2. Manufacturing Processes and Materials
3. Life-Cycle Integration
4. M&S Infrastructure.

Facilitator/scribe teams provided by IMTI will lead each group through a structured process to define and document:

- The **current state** of M&S application
- The **vision** for the future
- A **migration plan** (goals and requirements with a time basis) for achieving the vision
- **Critical capabilities** (top priority items) that must be addressed to assure success.

After the workshop, IMTI will distribute a copy of all the in-process outputs and within 30 days produce a draft roadmap for review and comment by the workshop participants. Two to 4 weeks is allocated for the review process. The draft document will be updated and a final version distributed to all workshop attendees in the mid-August timeframe.

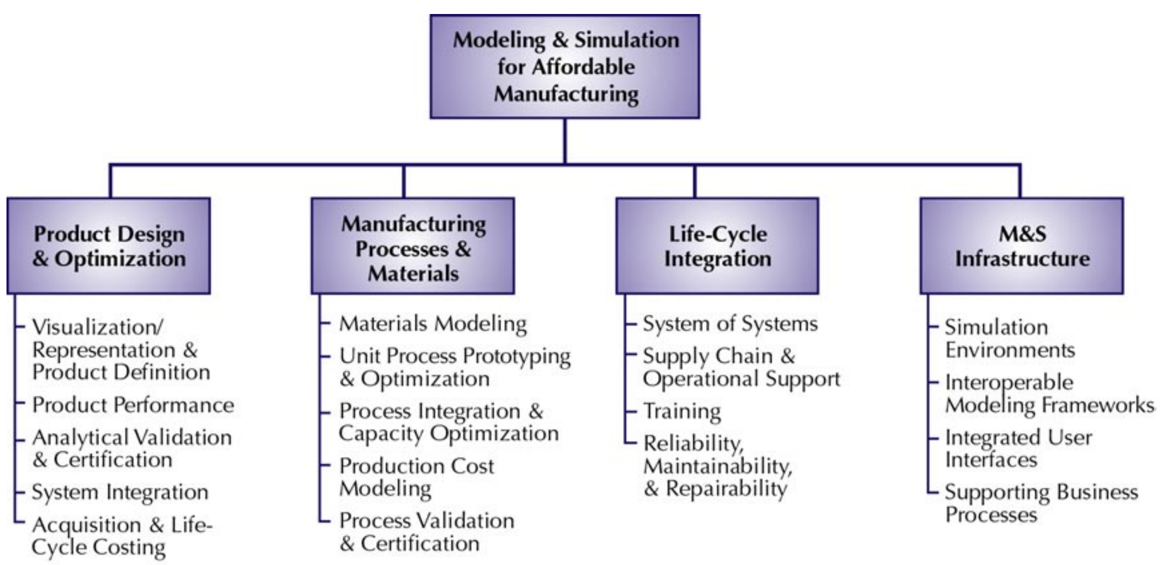

Figure 3. The Functional Model for the M&S Workshop and Technology Roadmap

Element Definitions
for the M&S Functional Model

Product Design & Optimization	
Visualization/ Representation & Product Definition	Includes all functionality associated with accurate visual portrayal/depiction of objects, processes, interactions, interfaces, and effects in a simulation environment, and underlying mathematical, science-based characterization and definition of modeled/simulated elements sufficient to accurately drive engineering, manufacturing, and other downstream processes. Includes the conceptualization, creation, capture, control, and depiction of the product and its associated features based on defined requirements and goals.
Product Performance	Includes all functionality associated with simulating and evaluating, in a virtual environment, performance attributes of the product such as size, weight, strength, material properties, operating environment, reliability, availability, maintainability, supportability, interoperability, and operational effectiveness attributes such as speed, lethality, survivability, aerodynamic performance, fluid dynamics, and similar attributes.
Analytical Validation & Certification	Includes all functionality associated with assuring that modeling and simulation codes, applications, and their products are accurate and verifiable in all respects.
System Integration	Includes modeling and simulation related to integration of complex, multi-element/multi-component/multi-subsystem products. Includes physical interconnection, mechanical and electrical interfaces, chemical/material interactions, software interfaces, component accessibility, system reliability and related dependencies, and similar attributes.
Acquisition & Life-Cycle Costing	Includes determination of product cost and associated affordability tradeoffs with various price and performance factors. Includes specific cost factors related to overall product life cycle attributes, including hardware and software development; testing and operational evaluation; manufacture; operation and maintenance factors such as sparing, replacement/repair, transport, training; and environmental requirements such as recycle, reuse, and disposal.
Manufacturing Processes & Materials	
Materials Modeling	Includes all aspects of M&S related to capture, representation (both visual and mathematical), and manipulation of material properties, including hardness, ductility, malleability, conductivity, crystalline structure, viscosity, reactivity, porosity, resistivity, conductivity, and similar attributes.
Unit Process Prototyping & Optimization	Includes all aspects of M&S related to evaluation of effectiveness, quality, and efficiency of a new or modified manufacturing process, and tailoring to realize the best process results within defined parameters. Includes manufacturability aspects such as material selection, part and feature complexity, tolerances, assembly interfaces, process options, and similar factors.
Process Integration & Capacity Optimization	Includes all aspects of M&S related to evaluation of multiple interrelated manufacturing processes intended to produce single or multiple products, and tailoring to achieve the best results (cost, quality, throughput, and time) for the total manufacturing activity.
Production Cost Modeling	Includes all aspects of M&S related to determination and optimization of the cost of manufacturing a given product or products.
Process Validation & Certification	Includes all aspects of M&S related to assuring that a manufacturing process or processes will perform consistently and reliably in accordance with the design intent and specifications.

(continued)

Element Definitions
for the M&S Functional Model (continued)

Life-Cycle Integration	
System of Systems	Includes all aspects of M&S related to evaluating and optimizing the attributes and performance of a product with respect to all other products with which it will interact in operational usage. Includes issues such as material and component compatibility and interchangeability, logistics support, physical and other interfaces, and the synergistic effectiveness of all interrelated systems to meet the customer's goals and requirements.
Supply Chain & Operational Support	Includes all aspects of M&S related to logistics with respect to design, optimization, and delivery of spares, consumables, and other support of the end product, including deployment and transport; provision of spares, consumables, and data; maintenance levels and concepts; and overall supportability.
Training	Includes all aspects of M&S related to design, optimization, and delivery of training for and with the end product for operational use and support, including virtual and constructive training and integration of virtual and constructive training with live training.
Reliability, Maintainability, & Repairability	Includes all aspects of M&S related to design and implementation of servicing of the delivered product, including product, component, and material service life; and concepts and designs for operational troubleshooting, problem isolation, repair/replacement, and refurbishment for return to operational status.
M&S Infrastructure	
Simulation Environments	Includes the common computing resources, methods, applications, tools, and codes needed to support any and all modeling and simulation requirements and enable integration and interaction of different applications and tools with necessary fidelity and speed.
Interoperable Modeling Frameworks	Includes all standards and protocols required to enable "plug and play" interaction of different modeling and simulation tools.
Integrated User Interfaces	Includes all visualization and command and control functionality required to enable users to operate and interact with modeling and simulation applications as an integrated element of any discipline/domain toolset. Includes the ability, for example, to invoke analytical simulation from directly within a CAD application.
Supporting Business Processes	Includes all aspects of enterprise management and program management and support that enable and facilitate the application of modeling and simulation capabilities across the various phases of the product life cycle, including concept definition, product and process design and validation, manufacturing execution, operational test and evaluation, and logistics support.

Appendix A
Workshop Logistics

Hotel and Reservation Information

The workshop will be held May 20-23 at the Sheraton Safari Hotel at Lake Buena Vista, Florida. The activities begin at 6 p.m. on Monday, May 20th with a dinner and an introduction to the workshop goals and methodology. If you have not already finalized your flight plans, you should plan to fly in by 4 pm to arrive in time for the evening dinner and work session.

If you have not already made your reservations at the Sheraton Safari, please call **1-800-423-3297** and be sure to tell them you are with the IMTI Modeling and Simulation Workshop.

The Sheraton Safari is one of the most unique hotels in the Sheraton system. Located just minutes away from such local attractions as the Magic Kingdom, Disney-MGM Studios, Epcot, and Disney's Animal Kingdom, the 489 room hotel includes 393 guest rooms, 90 safari suites, and six deluxe executive suites.

The workshop will adjourn at noon on Thursday, May 23 in time for afternoon flights. Please allow at least 2 hours for getting back to the airport, checking in, and getting through security.

Transportation

Lake Buena Vista is about 18 miles west of Orlando International airport. The Sheraton provides a shuttle service from the airport to the hotel (about a 30-minute ride). Cost is $10 per person, one way. You have to reserve at least 4 hours ahead by calling the hotel at **1-800-423-3297**. You can also take a taxi from the airport, but fares run around $20.

Directions to the Sheraton Safari Hotel from Orlando International Airport

1. Follow the signs when leaving the airport to SR 528/Beeline Expressway. This is a toll road.
2. Take 528 West to I-4 West for approximately 10 miles.
3. Take I-4 West for approximately 3 miles to Exit #27 Lake Buena Vista.
4. Turn right at the traffic light at the base of the off ramp on to SR 535/Apopka-Vineland Road North.
5. Follow SR 535 for approximately 1/4 of a mile to the second traffic light at Palm Parkway.
6. Hotel is on the corner on the right-hand side.

IMTI Contact Information

Mary Ann Merrell, IMTI, (865) 927-4135; e-mail merrel1@Bellsouth.net

Raymond Walker, IMTI, (561) 878-1701; e-mail raymwalk@aol.com

Richard Neal, IMTI, (865) 947-7000; e-mail imti1@msn.com

APPENDIX B
IMTI Workshop Staff

Richard E. Neal, IMTI Executive Director, has 30 years of experience in engineering and manufacturing technology development and management. He served with Lockheed Martin Energy Systems and its predecessor, Union Carbide, from 1970 to 1999 at the DOE Oak Ridge Y-12 Plant, in which capacity he led the Integrated Manufacturing Technology Roadmapping (IMTR) project (the precursor to IMTI) and predecessor programs such as the Next-Generation Manufacturing (NGM) project and Technologies Enabling Agile Manufacturing (TEAM). Mr. Neal serves on advisory boards for several academic institutions including the Technical Advisory Board for Pellissippi State Community College, the Industrial Engineering Advisory Board at the University of Tennessee, and the Modeling and Simulation Research Center Advisory Board for Georgia Tech University; and on manufacturing committees including a National Research Council Study of the Totally Integrated Munitions Enterprise (TIME) program of the U.S. Army, a Roundtable on Manufacturing in the U.S. and Canada, a visionary forum convened by the National Coalition for Advanced Manufacturing to seek consensus on manufacturing Grand Challenges, and several panels formed by the National Science and Technology Council. Mr. Neal has a BS and an MS in Electrical Engineering from the University of Tennessee.

William D. Brosey has held a number of positions at the DOE Oak Ridge Y-12 Plant, including Senior Development Staff, Group Leader, and Program Manager. He has been involved in both technology development and management in the Development Division of Y-12, and industrial partnering activities with the Textile and Transportation Industries through the Oak Ridge Centers for Manufacturing Technology (ORCMT). His involvement with manufacturing technology planning began with the NGM project, where he served on the Integration Team, Manufacturing Processes and Equipment team, and the Roadmapping Task Force. He also served as co-PI on the IMTR project. Mr. Brosey has a BS in Physics from David Lipscomb University and an MS in Materials Science from Vanderbilt University.

David Dilts is a professor in the Owen School of Business at Vanderbilt University, and serves as Director of the Management of Technology program. He has nearly 30 years of experience related to business management and manufacturing technology. He previously served as Professor of Management Sciences, University of Waterloo, Ontario, Canada, and as Director of the Waterloo Centre for Integrated Manufacturing. Dr. Dilts has published more than 120 journal articles, conference papers and presentations, book chapters, books and monographs in two main research areas: integrated extended enterprises and service quality, and has presented more than 30 invited papers to international firms and universities in the U.S., Europe, and Asia. He has a PhD in Production/Operations Management & Management Science and an MBA in Operations Research from the University of Oregon, and a BA in Business Administration from California Polytechnic State University.

A. Lynn Glover has 20 years of experience in research, development, and production in support of nuclear operations and technologies at DOE's Oak Ridge facilities. She has exceptional facilitation skills and her experience in this area ranges from production, environmental, computing, roadmapping, and strategic planning, including offsite facilitation in California, North Carolina, and Pennsylvania, and public service facilitation for the local Planning Commission and school board. Formal facilitation training includes training as a teacher in problem-solving, decision making, issue determination/clarification, and problem/opportunity analysis. Ms Glover has an MS in Physics from Kent State University and a BS in Physics from Longwood College.

Sara R. Jordan currently manages outsourced desktop computing support and web services for the DOE Y-12 Plant, providing infrastructure to meet stringent information security requirements. Major assignments over 20 years at DOE's Oak Ridge facilities include leadership of advanced information technology assessment and implementation projects; IT strategic planning and architecture work; and infrastructure streamlining and management efforts in a manufacturing facility environment. Prior to her Oak Ridge work, she helped form the Computer Science Department at UT–Knoxville, where she serves as an Adjunct Associate Professor. Dr. Jordan also served as an Information Technology resource, author, and facilitator for the IMTR project. She has a PhD and MS in Computer Science from the University of Wisconsin and a BS in Mathematics from Southern Methodist University.

Douglas F. Marks has 20 years of experience in project planning and business development across a wide range of fields including sensors and navigation systems, stealth platforms and sensors, guided missile systems and munitions, advanced simulation, electronic commerce, tactical aircraft, federal facilities management, manufacturing technology, radioactive and hazardous materials processing, image and signal processing, and information systems. His involvement in these areas spans all phases of the weapon system life-cycle, including conceptual development, engineering and manufacturing development, implementation planning, training, and production facility design, operations, and support. He served as chief writer and editor for the IMTR, NGM, and TEAM projects, and most recently served as lead writer and coordinator for the Training System segment of Lockheed Martin's winning Joint Strike Fighter (JSF) proposal. Mr. Marks has a BS in Communications from the University of Central Florida.

Mary Ann Merrell is IMTI's Business Manager, responsible for all accounting and financial reporting functions. She previously served as an Information Management Specialist at the DOE Y-12 Plant, and thus brings extensive experience in information management processes and systems supporting facility/site management as well as a wide range of business development units across DOE's Oak Ridge complex, including the National Security Programs Office, the ORNL Computational Physics program, the Y-12 Advanced Technologies organization, and ORCMT. She also serves as IMTI's coordinator for Information Management Strategy and for development of the MAST Knowledge Repository and related activities. Ms. Merrell has an MBA from Bristol University and an MLIS from the University of Tennessee.

Raymond M. Walker is the President of ARGO Enterprise Technologies, Inc., management consultants in cost reduction, strategic growth planning, and technology valuation. He combines over 28 years of experience in marine consulting engineering associated with aerospace materials and manufacturing technology development; steel structures, oil platforms, and floating work platforms; and recent management responsibility for supply chain integration and cost reduction initiatives for Pratt & Whitney. Mr. Walker has managed over $60 million of manufacturing technology initiatives in advanced materials processing technologies. He holds a BS in Ocean Engineering and graduate work towards a MBA from the Florida Institute of Technology.