Modeling and Simulation for Affordable Manufacturing

Technology Roadmapping Initiative

Co-sponsored by:

Air Force Research Laboratory
National Science Foundation

Facilitated by:

IMTI, Inc. – Integrated Manufacturing Technology Initiative

Overview

The Air Force Research Laboratory (Materials and Manufacturing Technology) and the National Science Foundation are co-sponsors of the Modeling and Simulation for Affordable Manufacturing - Technology Roadmapping Initiative. This initiative brings together a broad cross section of modeling and simulation (M&S) professionals from industry, academia, and government in a dynamic, cooperative environment with the charter to define a common vision and produce a technology roadmap for the development and application of revolutionary M&S methods and tools for affordable manufacturing.

The Modeling and Simulation for Affordable Manufacturing workshop was held in Orlando May 20-23, 2002. The resulting technology roadmap is in process and will be released in draft form mid-July for industry review. A copy of the roadmap can be obtained by contacting Doug Marks, IMTI, at dmarks1@cfl.rr.com or by downloading the document from the IMTI website (www.imti21.org) when it is posted.

On August 5-6, 2002 an action meeting will be held in Cincinnati as a follow-through to the Orlando Modeling & Simulation workshop. The purpose of the action meeting will be to define an action agenda, with the deliverable being a set of compelling white papers to be used in building programs and forming action groups.

Participants in the workshop and roadmapping effort include professionals from:

Aegis Technology Group
Altarum
Anteon
Arizona Center for Integrative Modeling & Simulation
Boeing
Carnegie Mellon
Chevron/Texaco
Cognition Corporation
Delmia Corporation
DH Brown & Associates
Ford
Georgia Tech
General Electric
General Motors
Honeywell
Lockheed Martin
Mississippi State
National Institute of Standards & Technology
Naval Postgraduate School Northrop Grumman
Penn State
Pratt & Whitney
Procter & Gamble
Princeton Synergetics
PTC
Raytheon
Rockwell Collins
Rolls Royce
RPI
Sandia National Lab
Simmetrix
Stevens Institute of Technology
TechSolve
Tennessee Tech
Tinker Air Force Base
University of Minnesota
UTRC
Vought

Background

Business Drivers for Improved Modeling & Simulation

Despite significant progress in recent years, defense acquisition span time remains 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, and 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; however, this vision does not extend much below the identification of virtual prototyping and virtual field-testing as tools for streamlining the development process.

Better integration of design and manufacturing 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 toward 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 operations 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 design (not just the product itself, but all of the infrastructure that supports it across its life) 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” (*Integrated Manufacturing Simulation for Affordability*, A White Paper, AFRL, March 2001).

A certain percentage of design change is unavoidable – requirements do evolve 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 costs.

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 research and development (R&D) programs. The following listing identifies a few of the notable activities as of March 2001.

Major Federal Initiatives in Modeling and Simulation

Advanced Engineering Environments – National Research Council
Defense Manufacturing in 2010 and Beyond – National Research Council
Engineering of Complex Systems (ECS) – Office of Naval Research
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 development and application of M&S, there is still much to do. M&S applications have revolutionized product design over the last two decades, and 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:

- Physical representation
- New and improved tools
- Database integration
- Ease of use

- Training.

Although there has been a significant increase in the capabilities of commercial 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, use of feature-driven designs and knowledge bases can significantly decrease modeling time. Tools that support multifunction optimization, process planning as a byproduct 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 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 significant reductions in design time and for accelerating the development and insertion of new materials and manufacturing processes into the future product realization environment.

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 suites; however, this does not support individual tool selection and is certainly not “open”. By developing and applying open standards to appropriate design and analysis applications and outputs, the M&S vendor community can provide a more flexible environment that supports 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, including 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 operate them. Employing immersive environments and desktop visualization techniques along with a rapid modeling capability will significantly improve usability. With these improvements, the training process becomes less cumbersome and reduces or eliminates the requirement for M&S specialists.

A recent report 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 to 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).

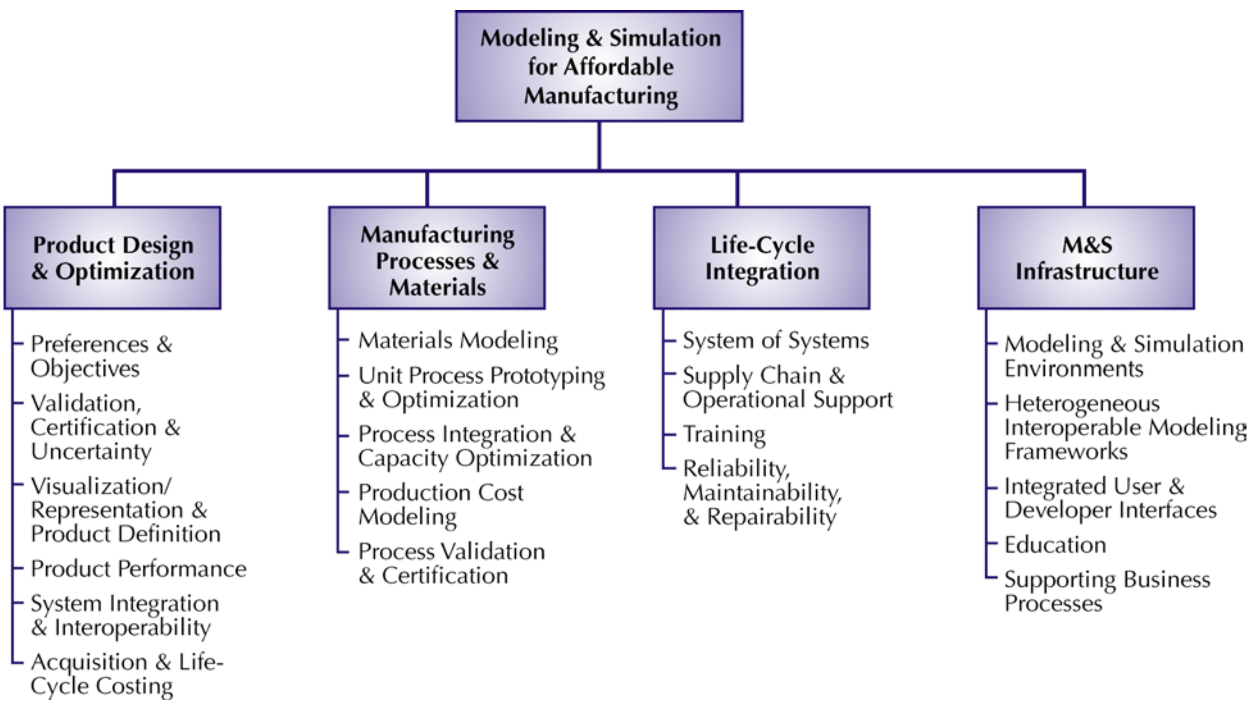
Technology Roadmapping Process

The Modeling and Simulation for Affordable Manufacturing workshop and technology roadmapping effort is being facilitated by the Integrated Manufacturing Technology Initiative, Inc. (IMTI), a non-profit industry/
academia/government partnership whose mission is to facilitate technology research and development that benefits the nation's manufacturing infrastructure. IMTI was formed in January 2000 by agreement of five government agencies (DoD, DOE, NSF, NASA, and DOC) and several leading corporations including Ford, Rockwell Collins, Procter & Gamble, and Chevron.

IMTI has developed a robust process, based on a structured methodology, for creating comprehensive technology roadmaps. This methodology is described in the following paragraphs and is the process being followed in developing the Modeling and Simulation for Affordable Manufacturing technology roadmap.

Functional Model

The IMTI process begins with the creation of an initial functional model of a subject area. The process identifies all of the functions an enterprise must perform in order to execute its missions. This assures that the resulting roadmap focuses on identifying the capabilities required to enhance the performance of those functions.



The M&S for Affordable Manufacturing functional model provides a hierarchical, logical framework for analysis of technology requirements.

The next stage of the roadmapping process is to extend and validate the functional model through review and discussion with subject-matter experts. This is done through informal contacts, widespread dissemination in the industry sector, and as part of a structured workshop process. This assures that the model is accurate, comprehensive, and logical in structure. With this validation, the model and a review of research related to the subject area provide the backbone for a prereading package that prepares the selected participants for the workshop process.

Workshop

With the functional model validated and the attendees prepared, the workshop phase of the roadmapping process begins. Typically, a workshop runs 2 to 3 days and involves 30 to 60 experts representing a broad cross section of the technology user and developer communities. Participants divide into breakout groups of 8 to 15 persons, with each group assigned to one Element of the functional model. Each group is staffed by a trained facilitator who leads the process, and is supported by a professional "scribe" who documents the group consensus at each step of the process in a pre-established roadmap template.

The ultimate objective of the workshop is to develop a rich vision of the future state of practice for the subject area, and then define the specific Goals and Requirements to achieve that vision.

The first step in the workshop is to define attributes of the Current State of practice and art for every Element in the functional model. While this includes the identification of best practices, the primary objective of the Current State Assessment is to identify deficiencies and barriers that must be overcome to achieve success.

The next step is to define the Future State Vision for each functional Element. The Vision step answers the question, "If this function were perfect, what would be its attributes?" Attendees are asked to ignore the constraints of current technologies and practices and envision themselves in the future performing the function in the very best way possible.

With the Visions defined, the next step is to identify the Goals that must be achieved to attain each Vision – to bridge the gap from where we are today to where we want to be in the future. This is the start of the process of defining the "migration strategy." The Goals are scripted as well-defined capability statements. A functional Element may have only a few Goals that must be achieved to attain the Vision, or may have a dozen or more.

With the Goals defined, the Requirements to achieve each Goal are identified. The Requirements statements define specific actions to develop the capabilities required to meet the Goal. The objective of a Requirement is to provide sufficient definition and clarity to organize a collaborative R&D project that will deliver a new system, a new tool, a new product, or a new capability that can be implemented across an entire industry sector, or across many different sectors.

Collectively, the Goals and Requirements can be time-phased to provide a baseline plan for performing the required R&D. The Visions/Goals/Requirements methodology is repeated for each Element and Sub-Element of the functional model. In this way, a complete technology roadmap for the topic area is produced.

Advantages of this methodology include the ability to quickly and efficiently convert the workshop notes to an easily recognized compilation that is "owned" by the participants. Further advantage is gained through the ease of indexing for web-based distribution and analysis. For example, the hierarchical structure of the roadmap document readily lends itself to a mapping of ongoing government and industry R&D projects against specific roadmap goals.

The final step in the workshop process is prioritization. As a precursor to implementation, it is important to determine the recurring and most compelling themes for immediate attention. This is accomplished through a process of individual scoring and group consensus to select the "critical capabilities" for priority emphasis. The decision processes for prioritization, the number and structure of the priority themes, and the disposition of the themes vary with each application. The primary objective is to define a project slate of funded activities that will execute the plan and realize the vision.

Modeling and Simulation for Affordable Manufacturing Workshop

Top Goals

At the conclusion of the Modeling and Simulation for Affordable Manufacturing workshop, each of the four breakout teams – Product Design & Optimization, Manufacturing Processes & Materials, Life-Cycle Support, and M&S Infrastructure – processed their content to identify the top goals for R&D focus. The combined workshop group then processed the individual team inputs to prioritize the identified goals.

A listing of the goals sorted by the number of votes received in the group prioritization process is shown below.

Following the prioritization activity, the workshop teams reconvened to process through subsets of the highest-scored goals, with the objective to identify actions that can and should be taken in order to focus industry and government resources on their accomplishment. These plans are currently being refined through follow-on workshops and will be published with the draft roadmap document.

Top Goals - Sorted by Voting

Team	Goal	Votes
1 - Design	Develop techniques to support the automated generation of models at various levels of abstraction	48
1 - Design	Complete awareness of cost factors, supporting decision making early and throughout the design and manufacturing lifecycle	31
3 - Life Cycle	Develop and deliver a scaleable, comprehensive product life-cycle model with enabling architecture and data structures tailorable to all sectors and integratable across all levels of the supply chain	27
1 - Design	Establish seamless integration of modeling systems to enable multi-discipline optimization delivering impact early in the design process	23
1 - Design	Establish rigorous mathematical models to analyze uncertainty, and provide validation and certification in M&S including the quantification of uncertainty in models	19
1 - Design	Develop object-driven data schema from which models are generated, assuring interoperability and reuse (includes common feature sets)	18
2 - Mfg Processes	Create a tool to produce a process plan for manufacturing operations	18
4 - Infrastructure	Develop a solution to solve the interoperability problem of new, legacy, and proprietary systems and models	18
1 - Design	Develop systems that maximize the effectiveness of testing through the use of performance models realizing “surprise free” product performance	16
2 - Mfg Processes	Develop an interoperable framework for the integration of materials, material processing, and manufacturing models	16
2 - Mfg Processes	Develop interoperable models for the integration of materials, material processing, and manufacturing simulations	16
2 - Mfg Processes	Create a tool to evaluate process capability to determine producibility of features, resource capabilities, and process repeatability	16

Team	Goal	Votes
4 - Infrastructure	Establish extensible process and guidance for flexible, ongoing conceptual model management	16
4 - Infrastructure	Establish an efficient means to educate and train all stakeholders on the fundamental concepts, capabilities, and limitations of M&S, so they are able to critically and effectively apply M&S infrastructure to solve problems and contribute to the growth of corporate M&S knowledge and capability	16
1 - Design	Develop a heterogeneous open architecture environment that provides defined interfaces between elements (from cradle to grave); the environment merges elements of operational analysis, mechanical systems, variability, electrical, manufacturing, etc	15
1 - Design	Quantify sensitivity to variations and define limits in design and manufacturing robustness leading to common models for robustness evaluation	14
2 - Mfg Processes	Create an interoperable framework for enterprise models that supports manufacturing and business decision making across the extended enterprise	13
3 - Life Cycle	Develop and execute strategies to integrate M&S as "the way business is done" into acquisition & O&M culture	13
4 - Infrastructure	Provide structure that supports repartitioning across disciplines, providing different views and configurations, with different systems interfaces	12
4 - Infrastructure	Make M&S pervasive across the organization, including establishing ROI requirements, maximizing revenue opportunities, and managing risk	12
1 - Design	Develop a modeling capability that refines preferences to create definitive design parameters/objectives in a trade-off environment	11
4 - Infrastructure	Make M&S infrastructure and environment be understood as the primal and most strategic investment analysis tool in the organization; gain support for M&S approach by showing proof	11
4 - Infrastructure	To accommodate different users' requirements at different times/contexts, provide user interfaces that are dynamically reconfigurable according to the context of use and that include accommodating the type of device being used (PC, phone, etc.)	10
2 - Mfg Processes	Develop mechanisms to support verification and validation for materials and manufacturing process simulations	9
3 - Life Cycle	Develop and deliver M&S capability to determine, in design phase, the life-cycle cost/risk/ performance impacts of decisions about reliability, maintainability, supportability, etc.	9
3 - Life Cycle	Develop technologies and tools enabling integration of real-time data into life-cycle models	8
3 - Life Cycle	Develop and deliver technologies enabling model-based control of life-cycle functions	7
4 - Infrastructure	To minimize training and maximize decision-making efficiency, provide a generic GUI/cockpit/dashboard for the operation of multiple, heterogeneous distributed models with multiple levels of utility/complexity	7
2 - Mfg Processes	Develop the methodology/ interface for systematically translating requirements for material selection	5
2 - Mfg Processes	Create methodologies for the mitigation of risk for the selection of new materials	5
3 - Life Cycle	Develop a comprehensive virtual test environment integrating all life-cycle factors and considerations	5

Team	Goal	Votes
3 - Life Cycle	Develop and implement techniques & technologies driving evolution of an M&S enabled & empowered workforce	4
4 - Infrastructure	Develop test methods to arrive at and validate methods of interoperability	3
1 - Design	Provide intuitive systems that represent the human decision process and enable effective interaction with modeling systems	2
2 - Mfg Processes	Mature and expand existing simulation technologies to be used by practitioners to make underlying technology more transparent	0
2 - Mfg Processes	Develop multi-dimensional object-oriented cost models (models carry all elements of cost)	0
4 - Infrastructure	Dramatically reduce the amount of time and labor and expertise required to develop, populate, and use integrated models and simulations to reach a feasible, producible solution	0