



Final Report of the Subcommittee on the Identification of Modeling and Simulation Capabilities by Acquisition Life Cycle Phase (IMSCALCP)

**NDIA Systems Engineering Division
M&S Committee**

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Executive Summary

Background

During the Fall of 2011, discussions were held among the NDIA Systems Engineering Division's Modeling and Simulation (M&S) Committee leadership and representatives of the Office of the Deputy Assistant Secretary of Defense (Systems Engineering / Systems Analysis) [ODASD(SE/SA)] concerning M&S topics of interest. What emerged was an interest in identifying what M&S capabilities are needed/used in each phase of the Defense Acquisition Life Cycle. Similar discussions took place among the M&S Committee's leadership and the leadership of the NDIA Systems Engineering Division, which resulted in the identification of an interest in identifying prevalent M&S tools used in systems engineering activities during the Acquisition Life Cycle. After discussions at the NDIA Systems Engineering (SE) Division's Strategic Planning Meeting in December 2011, the M&S Committee took the action to perform a study on the Identification of Modeling and Simulation Capabilities by Acquisition Life Cycle Phase.

Process

At its February 2012 meeting, the M&S Committee formed a subcommittee with a charter to examine the Defense Acquisition Life Cycle, and identify in each phase of the life cycle the systems engineering and acquisition functions that need to be performed that can be enabled by the use of M&S; for each engineering/acquisition function, identify specific existing M&S capabilities that can contribute to the performance of that function; and, for each M&S capability, identify government and industry M&S tools that are prevalent in helping to provide that capability. The subcommittee met bi-weekly by telephone for about 15 months, and also held face-to-face meetings as part of the M&S Committee meetings that occurred during the term of the study. Over the course of the study, 30 professionals participated, performing individual research and collecting data in a form that could be combined in a uniform fashion.

Issues Encountered

Very early during the subcommittee's work, it became apparent that there was no accepted taxonomy for describing M&S capabilities. In order to complete its work, the subcommittee developed a preliminary set of M&S capability descriptions. It later became apparent that it was difficult for the subcommittee to establish, in any authoritative way, which M&S tools were "prevalent" in providing particular M&S capabilities. As a result, the subcommittee decided that its final product would cite only "example" M&S tools, based on the personal knowledge of the subcommittee members.

It also became evident that some M&S capabilities supported multiple acquisition activities, and some M&S tools provided multiple M&S capabilities. Therefore, a single two-dimensional spreadsheet did not provide an efficient way of representing the relationships, since individual M&S capabilities and, certainly, individual M&S tools, would appear in multiple, perhaps very many, rows of the spreadsheet.

Structure of the Information

One of the principal goals of the study was to produce a final product that would be usable by both program managers and systems engineers. The subcommittee considered a relational database structure, or an even more complete ontology as a form of representation. An ontology was felt to be overly complex. A database was felt to be appropriate in structuring the information, but most database tools, even Microsoft Access, are not typically used on a day-to-day basis by most program managers and engineers.

The subcommittee, did, however, want to avoid replication of data entries, which would have made any subsequent updates prone to error if not all occurrences of a single data entry were found and updated consistently. As a result, the subcommittee decided on a four-worksheet Excel workbook, with a single worksheet for each set of associations. Links between the worksheets were used so that all unique data elements would be entered in only one cell in one worksheet.

Acquisition activities (sometimes in multiple levels, depending on the life cycle phase) are entered in the “Activities-to-Capabilities Map” spreadsheet. For each activity that is supported by one or more M&S capabilities, there is a link to each of those capabilities (often at an aggregated, or category, level), which are entered in the “M&S-Capabilities-to-Tools Map” spreadsheet. Most of the M&S capabilities listed in that spreadsheet belong to a larger category of M&S capabilities, and are linked in the “M&S Capabilities Categories” spreadsheet. Also, each M&S capability often has multiple links to example M&S tool entries in the “M&S Tools List” spreadsheet. The primary entry for each M&S tool in that spreadsheet is its acronym, if it has one, with the full name listed in the adjacent cell in the row.

Results of the Study

The subcommittee identified 103 M&S capabilities, most of which were included in 11 major categories. A definition was developed for each capability, sometimes at just the category level. Wherever possible, subcommittee members attempted to identify an authoritative source for each definition, using it verbatim if possible, or adapting it, if necessary. In some instances, an authoritative definition could not be found, in which case one was constructed for the purposes of the study.

Acquisition activities were identified for each of the five phases of the Acquisition Life Cycle. In some cases, based on work done by other groups, the activities were able to be detailed into two or three hierarchical levels. For each phase, a mapping of the lowest level of activities was made to the M&S capabilities that can aid in performing those activities. A separate mapping was made of M&S capabilities to 148 example M&S tools that can provide these capabilities. There was no attempt, however, to provide an exhaustive list of example tools, as existing M&S catalogs and repositories can be consulted for the capabilities of thousands of specific M&S tools.

Recommended Future Activities

Unlike many studies, the primary product of this study is not simply a final text report, but the initial version of an Excel workbook that can be updated, as desired by the systems engineering M&S community of interest, so that it becomes a living document. The intent is to post this spreadsheet along with this report on the M&S Committee's web site, so that it can be downloaded, utilized, and updated as needed. In order to provide configuration management, the M&S Committee's leadership will act as the focal point to receive suggested updates, and to post appropriate updates periodically, perhaps on an annual basis.

Although the subcommittee developed what it believes to be a fairly level set of M&S capability descriptions, it is believed that development of a complete taxonomy of M&S Capabilities would be beneficial. However, to do so in an authoritative way that gives even treatment to all the areas of modeling and simulation used in systems engineering is too large an effort for a small number of volunteers. A larger DoD-resourced effort with a well-defined set of requirements is felt to be needed to accomplish this.



Genesis of the Topic

- **Discussions between NDIA SE M&S Committee leadership and ODASD(SE/SA) representatives, November 2011**
 - Interest in M&S Capabilities by Acquisition Life Cycle Phase
- **Discussions with NDIA SE Division leadership, November 2011**
 - Interest in identifying M&S tools prevalent in systems engineering
- **Proposed 2012 task included in NDIA SE M&S Committee report at December NDIA SE Division Planning Meeting:**
 - “Assessment of M&S capabilities, and prevalence of specific M&S tools, used in each phase of the Systems Acquisition process”
- **U.S. Air Force (Col Ogawa) presentation at December NDIA SE Division Planning Meeting:**
 - Citation of Objective 2.2 in U.S. Air Force SE Strategic Plan on “Standard practices, tools, metrics ... Focus on modeling & simulation across life cycle”
- **Resulting action item from SE Division planning meeting:**
 - “(NDIA SED) Consider: state of the art in M&S, M&S across the life cycle. Reusable architectures. Physics-based modeling, support architectures w/ M&S.”

Genesis of the Topic

During the Fall of 2011, discussions were held among the NDIA Systems Engineering Division’s Modeling and Simulation (M&S) Committee leadership and representatives of the Office of the Deputy Assistant Secretary of Defense (Systems Engineering / Systems Analysis) [ODASD(SE/SA)] concerning M&S topics of interest. What emerged was an interest in identifying what M&S **capabilities** are needed/used in each phase of the Defense Acquisition Life Cycle. Similar discussions took place among the M&S Committee’s leadership and the leadership of the NDIA Systems Engineering Division, which resulted in the identification of an interest in identifying **prevalent M&S tools** used in systems engineering activities during the Acquisition Life Cycle.

The above dual tasking was proposed by the M&S Committee leadership at the NDIA Systems Engineering (SE) Division’s Strategic Planning Meeting in December 2011. At that meeting, the U.S. Air Force presentation cited an objective from the U.S. Air Force Systems Engineering Strategic Plan regarding standard practices, tools, and metrics with a focus on M&S across the life cycle. The net result was an action item from the meeting to proceed, with additional guidance to consider reusable architectures, physics-based modeling and support of architectures with M&S.



Subcommittee Charter

- **Consider the state of the art and practice of modeling and simulation (M&S) across the Defense Systems Acquisition Life Cycle**
- **For each phase of the life cycle, identify systems engineering and acquisition functions that need to be performed that can be enabled by the use of M&S**
- **For each engineering/acquisition function, identify specific existing M&S capabilities that can contribute to the performance of that function**
- **For each M&S capability, identify government and industry M&S tools that are prevalent in helping to provide that capability**
- **In performing the above activities, keep in mind such things as reusable architectures, support of architectures using M&S, physics-based modeling, and similar activities that are enabled by the use of M&S**

NDIA M&S Committee Subcommittee on the Topic

Subcommittee Charter

During the February 2012 meeting of the M&S Committee, the formation of a subcommittee was initiated to perform the effort, titled the Subcommittee on Identification of M&S Capabilities by Acquisition Life Cycle Phase. The first activity for the subcommittee was to develop a charter to specify the scope of the investigation and the information and recommendations that would be developed by the subcommittee. The charter took the guidance from the December 2011 SE Division meeting, and delineated a three-step breakdown for its activities:

- For each phase of the life cycle, identify systems engineering and acquisition functions that need to be performed that can be enabled by the use of M&S;
- For each engineering/acquisition function, identify specific existing M&S capabilities that can contribute to the performance of that function; and
- For each M&S capability, identify government and industry M&S tools that are prevalent in helping to provide that capability.



Subcommittee Participants

- Jim Coolahan (JHU)
- Jeff Bergenthal (JHU/APL)
- David Allsop (Boeing)
- Bill Besch (Lockheed Martin)
- Chuck Burdick (Innovative Decisions)
- Chris Eastman (Lockheed Martin)
- Tim Ewart (US Air Force)
- Kevin Flood (AGI)
- George Harris (US Army)
- Allen Harvey (TASC)
- Greg Haun (AGI)
- George Hazelrigg (NSF)
- Michael Heaphy (Booz Allen Hamilton)
- Ken ("Crash") Konwin (Booz Allen Hamilton)
- Robert Leach (Dynamic Animation Systems)
- John Lohse (Raytheon)
- Margaret Loper (GTRI)
- Favio Lopez (Trideum)
- Tammy McNeley (Lockheed Martin)
- Joe McDonnell (Dynamic Animation Systems)
- Kirk Michealson (Lockheed Martin)
- Katherine L. Morse (JHU/APL)
- Dennis Pippy (SAF/AQ Ctr)
- Greg Pollari (Rockwell Collins)
- Hans Polzer
- Steve Reading (Cutlass Systems Engineering)
- Anne Ricks (Cutlass Systems Engineering)
- Frank Salvatore (DRC)
- James Trbovich (Cutlass Systems Engineering)
- Jeff Wallace (Intelligent Integration)

Subcommittee Participants

The names of all individuals who participated in subcommittee activities at any point in the process are shown in the slide above. Each individual's organizational affiliation is shown in parentheses. A large majority of the above-listed individuals contributed directly to what eventually became a multi-spreadsheet Excel workbook that contains an electronically modifiable version of the "final" product of the subcommittee's efforts, which can be maintained and updated over time to the degree that individuals are motivated to do so, and as their resources permit.



Subcommittee Process

- **Initial subcommittee formation at 21 February 2012 NDIA SE M&S Committee meeting**
- **Bi-weekly teleconferences scheduled**
- **Data collection spreadsheet designed and distributed**
- **Sources of information identified**
- **Different sources and parts of the problem researched by individual subcommittee members**
- **Face-to-face meetings at numerous NDIA SE M&S Committee meetings**
- **Presentations by industry team members in bi-weekly teleconferences, August – October 2012**
- **Construction and evolution of master Excel workbook, linking acquisition activities, M&S capabilities, and example M&S tools – Spring/Summer 2013**

Subcommittee Process

The kickoff meeting of the subcommittee was held on 21 February 2012. Thereafter, the subcommittee began meeting telephonically on a bi-weekly basis. A data collection spreadsheet (shown later in this report) was designed and distributed to subcommittee members. Several sources of information were identified (also shown later in this report). Subcommittee members did research on different parts of the subject matter. In addition to the bi-weekly telephonic meetings, face-to-face meetings were conducted as part of the M&S Committee meetings that occurred during the term of the study. To supplement the individual research, a number of subcommittee members from private industry gave presentations on M&S activities in systems engineering within their companies. Finally, starting in the Spring of 2013, the subcommittee constructed and iterated a multi-worksheet Excel workbook (excerpts shown later) that identified acquisition activities, M&S capabilities, and example M&S tools, and linked them with one another to show relationships among them.



Some Sources of Information

- Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System (the Defense Acquisition University “wall chart”), Jun 2010
- A Roadmap for Simulation Based Acquisition (Appendix C), Dec 1998
- NDIA SE M&S Committee report, “M&S Support to the New DoD Acquisition Process,” Feb 2004
- Final Report, Study on Management Concepts for Broadly-Needed Modeling and Simulation Tools, Jun 2010
- DoD M&S Catalog
- CBA Handbook – A Guide for Implementing Capabilities-Based Analysis (CBA), Jun 2010
- “M&S Across the System Acquisition Life Cycle” (Campbell and Lashlee), 2010
- Materiel Solution Analysis Activities and Descriptions (Riski), Jun 2012
- Defense Acquisition Guidebook, <https://daq.dau.mil/Pages/Default.aspx>
- DOD Product Support Business Case Analysis Guidebook, 2011
- DoD M&S Glossary

Some Sources of Information

Selected References

The subcommittee conducted a broad search for information, based on each member’s areas of knowledge and expertise. The sources included DoD- and industry-funded studies over the past 15 years, DoD-funded catalogs and glossaries, official DoD publications, and technical papers published in the open literature. The above is a partial, certainly not exhaustive, list of sources of information. Additional sources of information, such as for adopting/constructing definitions of M&S capabilities, may be found in the aforementioned Excel workbook. Finally, some information, such as example M&S tools came simply from personal knowledge of the subcommittee members.



Data Collection Template

System Acquisition Activities		Supporting M&S Capabilities		Prevalent M&S Tools	
Activity	Source Document	Capability	Source Document	Acronym	Name

Data Collection Template

In order to gather information from multiple persons and sources in a form that could be readily combined and synthesized, a data collection template was designed in Excel. The intent was to capture system acquisition activities, with the source of those activities documented, along with potentially multiple M&S capabilities that could be used to support those activities, again with the source of the M&S capability to acquisition activity linkage documented. Finally, the desire was to identify a few “prevalent” M&S tools that could be used to provide each M&S capability. The intent was certainly not to duplicate more comprehensive sources of information on M&S tools, such as the DoD M&S Catalog, which has entries numbering in the thousands. Nor was the intent to endorse any particular M&S tool as the most appropriate for a particular application.

From the design of the above data collection template, it is clear that the expectation was that there would be a “one-to-many” relationship between acquisition activities and M&S capabilities, and yet another one-to-many relationship between M&S capabilities and prevalent M&S tools.



Issues Encountered (1 of 2)

- **There is no accepted taxonomy for describing “M&S Capabilities”**
 - **Need to have a “level” set of descriptors**
 - ◆ Not too high-level (e.g., “Constructive simulations”)
 - ◆ Not too low-level (e.g., “EADSIM simulation”)
- **As an adjunct to this study, needed to either develop a taxonomy, or advocate for its creation**
- **It was too difficult for the subcommittee to determine what M&S tools are “prevalent” (wording in charter)**
 - **Decided to cite “example” M&S tools**

Issues Encountered

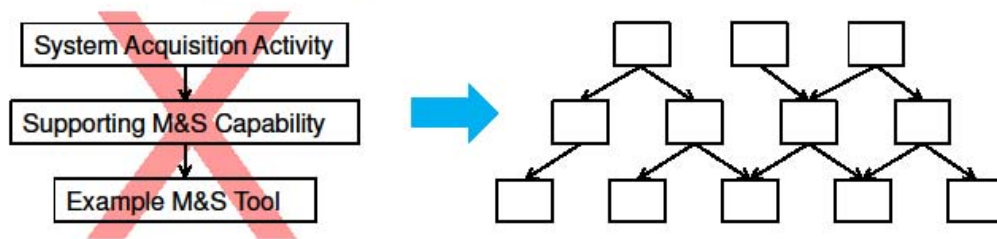
As the subcommittee’s work progressed, several issues were encountered that needed to be addressed. It became apparent very early in the committee’s work that there was no taxonomy for describing M&S capabilities. Over the years, models and simulations have been created and evolved within various communities of interest, have been described individually, and have sometimes been binned into categories based on particular parameters. For example, historically, military simulations have been categorized into four (or sometimes more) levels of aggregation, typically referred to as engineering, engagement, mission and campaign. But such categorizations have not been comprehensive or sufficiently well-defined to be very useful for informing systems engineers as to whether a particular category of M&S tools might be appropriate for a particular application. In order to complete its work, the subcommittee developed a preliminary taxonomy (described later), but believes that a more comprehensive consensus-based effort is needed to develop a more authoritative taxonomy.

Additionally, as the subcommittee continued its work, there was a realization that it was difficult for the subcommittee to establish, in any authoritative way, which M&S tools were “prevalent” in providing particular M&S capabilities. Usage data, particularly for commercially-developed M&S tools, is generally not published. As a result, the subcommittee decided that its final product would cite only “example” M&S tools, based on the personal knowledge of the subcommittee members.



Issues Encountered (2 of 2)

- Mapping of “system acquisition activities in a phase” to “supporting M&S capabilities” to “example M&S tools” is not a hierarchical tree structure
 - Some supporting M&S capabilities could be applicable in multiple system acquisition activities in multiple phases
 - Some example M&S tools could be used in providing multiple M&S capabilities
 - A two-dimensional spreadsheet is not a good way of representing the structure, since there will be many replications
 - ♦ Is a relational database a sufficient structure?
 - ♦ Is an ontology necessary?



Issues Encountered (continued)

As mentioned earlier, the Data Collection Template spreadsheet anticipated a one-to-many relationship between acquisition activities and M&S capabilities, and between M&S capabilities and example M&S tools. As work progressed, it became evident that some M&S capabilities supported multiple acquisition activities, and some M&S tools provided multiple M&S capabilities. In mathematical terms, the relationships could not be expressed as a hierarchical tree structure, but rather represented an acyclic directed graph.

As a result, a single two-dimensional spreadsheet is not an efficient way of representing the relationships, since individual M&S capabilities and, certainly, individual M&S tools, would appear in multiple, perhaps very many, rows of the spreadsheet. This would also create potential configuration management difficulties if, for example, the name of an M&S capability were changed. The subcommittee considered a relational database structure, or an even more complete ontology as a form of representation. In the end, however, a multi-worksheet Excel workbook was selected, as described later in this report.



Industry Briefings to the Subcommittee

- **Two distinct Industry groups:**
 - **Providers of Commercial-Off-The-Shelf models and simulations**
 - **System developers who use M&S**
- **M&S capabilities are broadly used across all phases of the acquisition life cycle**
 - **Use of an M&S capability is generally not limited to a single phase**
 - **Models and simulations are often linked together to achieve the desired capability**
- **Challenges remain to more fully exploiting the value of M&S across the acquisition life cycle**
 - **Data availability and interchange**
 - **Confidence, trust, relevancy, ROI**
 - **Etc.**

Industry Inputs

To supplement each subcommittee members' individual research, a number of subcommittee members from private industry gave presentations on M&S activities in systems engineering within their companies. In general, industry participants fell into two groups: providers of commercial-off-the-shelf (COTS) M&S tools, and system developers who use M&S tools. It was generally found that M&S capabilities are used throughout the acquisition life cycle, and that individual M&S capabilities are usually used in more than one phase of the life cycle. Furthermore, it was found that multiple models and simulations are often linked together to produce the required M&S capability, with the outputs of one model/simulation manipulated to form the input for another model/simulation, and sometimes with multiple simulations linked together interactively at run-time. Nevertheless, there remain a number of challenges (as listed above) in more fully exploiting the value of M&S across the life cycle.

The following two charts, provided by Analytical Graphics, Inc., and Lockheed Martin, respectively, illustrate perspectives of M&S tool developers and M&S tool users.



Use of COTS M&S During Technology Development Phase

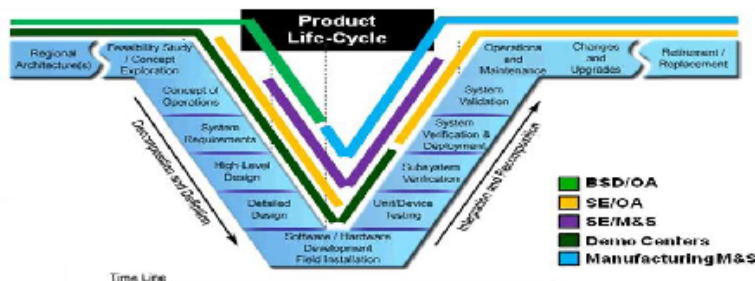
Objective: Reduce technical risks

- ✓ System integration
- ✓ Design
- ✓ Prototyping
- ✓ Military utility assessment
- ✓ Model environment and demonstrate technology
- ✓ Interoperability & supportability analysis
- ✓ Operational suitability
 - Assess manufacturing risks
 - Industrial/Manufacturing capability & readiness assessment
 - Life-cycle sustainment planning
- ✓ Survivability analysis
- ✓ Update AoA
- ✓ Affordability assessment
- ✓ Estimate manpower/cost
- ✓ Model system to performance specifications
- ✓ Design/ Develop System Concepts
- ✓ System threat assessment
 - Environment, Safety, and Occupational Health (ESOH) Models
- ✓ Human System Integration
- ✓ T&E Planning



Model & Simulation Usage Areas

- Business Support & Operations Analysis
- Demo Centers
- Model-Based Systems Engineering (MBSE)
- Computer Aided Design (CAD)
- Product Data and Lifecycle Management
- Manufacturing M&S
- Training & Education



M&S Deeply Engrained w/in ALL Lines of Business and Throughout Life-Cycle



Structuring the Information for Use

- **Goal was to have a final product that could be readily used by program managers (PMs) and systems engineers (SEs)**
 - **Ontology was felt to be overly complex (more in the domain of information specialists)**
 - **Database was felt to be appropriate, but tools (e.g., Access), although readily available, are not typically used on a day-to-day basis by most PMs and SEs**
- **Wanted to avoid replication of data entries, to avoid inadvertent errors / inconsistencies during subsequent updates**
- **Decided on a multi-worksheet Excel workbook**
 - **One worksheet for each logical set of associations (e.g., acquisition activities to M&S capabilities)**
 - **Links between worksheets so that all unique data elements exist in only one cell**

Structure of the Information in an Excel Workbook

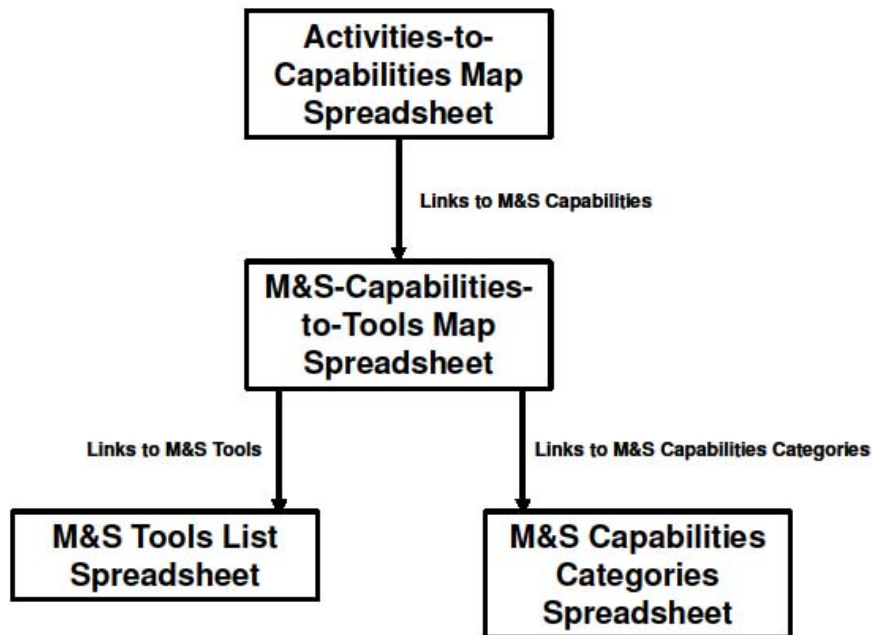
Structuring the Information for Use

One of the principal goals of the study was to produce a final product that would be usable by both program managers and systems engineers. Although the subcommittee considered developing one, an ontology was felt to be overly complex, something more within the capabilities of information specialists, rather than program managers and systems engineers. A database was felt to be appropriate in structuring the information, but most database tools, even Microsoft Access, are not typically used on a day-to-day basis by most program managers and engineers.

The subcommittee, did, however, want to avoid replication of data entries, which would have made any subsequent updates prone to error if not all occurrences of a single data entry were found and updated consistently. As a result, the subcommittee decided on a multi-worksheet Excel workbook, with a single worksheet for each set of associations. Links between the worksheets were used so that all unique data elements would be entered in only one cell in one worksheet.



Structure of the Excel Workbook



Structure of the Excel Workbook

The above figure shows the four worksheets in the Excel workbook, along with the links among them. Acquisition activities (sometimes in multiple levels, depending on the life cycle phase) are entered in the “Activities-to-Capabilities Map” spreadsheet. For each activity that is supported by one or more M&S capabilities, there is a link to each of those capabilities (often at an aggregated, or category, level), which are entered in the “M&S-Capabilities-to-Tools Map” spreadsheet. Most of the M&S capabilities listed in that spreadsheet belong to a larger category of M&S capabilities, as explained in the following section. To indicate these relationships, each of those M&S capabilities has a link to the appropriate M&S capability category entry in the “M&S Capabilities Categories” spreadsheet. Also, each M&S capability often has multiple links to example M&S tool entries in the “M&S Tools List” spreadsheet. The primary entry for each M&S tool in that spreadsheet is its acronym, if it has one, with the full name listed in the adjacent cell in the row.

Results of the Study

The following subsections describe the results of the study. Included in the results are a listing of the M&S capabilities, and selected categories thereof, that were identified during the study, as well as definitions for selected M&S capability categories and individual M&S capabilities. The complete listing and definitions may be found in the Excel workbook that was produced in conjunction with the study.

The results also include excerpts from the Excel workbook that illustrate the acquisition activities for each phase of the Acquisition Life Cycle and the M&S capabilities (or M&S capability categories) that can be used as aids in those activities. Although not shown in the results by phase, there were a few M&S capabilities that the subcommittee felt went across all phases, which are listed in the Activities-to-Capabilities Map spreadsheet of the Excel workbook as General M&S Capabilities. These include capabilities such as simulation interoperability infrastructure and M&S catalogs and repositories

Finally, the results include excerpts from the Excel workbook that illustrate example M&S tools that can be used in providing the identified M&S capabilities.



M&S Capability Categories

- Campaign-level simulation
- Engagement-level simulation
 - Specific type dependent on system
- Human Systems M&S
 - Human factors modeling
 - Human-system integration simulation
- Maintenance training simulation
- Mission-level simulation
 - Specific type dependent on system
- Mission training simulation
- RAM modeling / simulation
 - Fault tree modeling
 - Obsolescence modeling
 - Reliability modeling
 - Supply chain modeling
 - ... (and more)
- Cost modeling
 - Disposal cost modeling
 - Investment cost modeling
 - O&S cost modeling
- Engineering-level simulation
 - ASIC/FPGA modeling and design
 - Communications modeling
 - Computational fluid dynamics simulation
 - Electromagnetic propagation modeling
 - Mechanical design modeling
 - Structural mechanics modeling
 - Thermal analysis simulation
 - ... (many more)
- Operator training simulation
- Virtual system simulation

M&S Capability Categories

As mentioned earlier, having found that there was no accepted taxonomy for M&S capabilities, the subcommittee developed a preliminary taxonomy for the purpose of this study. Although some capabilities could be rather readily described independently, it became apparent that many capabilities fell into categories. For example, cost modeling is a category that can be subdivided into separate cost modeling capabilities depending on what portion of the acquisition life cycle is being addressed. Additionally, the levels of the traditional military simulation “pyramid” can be considered as M&S capability categories, but these categories, particularly at the lower three levels (mission, engagement, and engineering) may not have sufficient meaning to be useful to a program manager or systems engineer for a specific program. So, mission-level modeling is better described by the specific mission area(s) being addressed by a system, engagement-level modeling by the type of system, and engineering-level modeling by the technologies employed in a system. Overall, the subcommittee identified eleven major categories of M&S capabilities, although it would certainly be possible to define others, depending on the organizing principle. These eleven categories are shown above, along with explanations and/or examples of the M&S capabilities included in each category. These same eleven categories populate the M&S Capabilities Categories spreadsheet in the Excel workbook.



Some M&S Capability Definitions (1 of 2)

M&S Capability Name	M&S Capability Category	M&S Capability definition/description	Definition Source (reference citation - state if verbatim or adapted from; or defined here)
Life-cycle cost modeling	Cost modeling	The modeling of total Government cost for a program over its full life, to include the cost of research and development, investment in mission and support equipment (hardware and software), initial inventories, training, data, facilities, etc., and the operating, support, and, where applicable, demilitarization, detoxification, or long term waste storage.	Adapted from: - AR 70-1, Ch 1-6.c. - DOD 5000.4-M, Para C3.3.7
Operations and support (O&S) cost modeling	Cost modeling	The modeling of materiel readiness and operational support costs to operate, maintain and support a fielded system (and its associated manpower and facilities).	Adapted from the DAG, Ch.3.7, Principles for Life-Cycle Cost Estimates; Para 3.7.1.3 Operating and Support (O&S) Cost Element Structure
Active protection system simulation	Engagement-level simulation	(Category-level definition) Simulation of a system in a limited scenario, such as one-on-one, few-on-few or sometimes many-on-many. Evaluates the effectiveness of an individual platform and its weapon systems against a specific target or enemy threat system. Relies on system performance, kinematics, and sensor performance from engineering-level simulations. Provides measures of system effectiveness for mission-level simulations.	Defense Systems Acquisition Management College, Acquisition Manager's Guide for the Use of Models and Simulations, September 1994.
Acoustic propagation modeling	Engineering-level simulation	(Category-level definition) Simulation of detailed engineering characteristics, to estimate measures of performance of components, subsystems, or systems; provides the basis for design trades.	Derived from Defense Systems Acquisition Management College, Acquisition Manager's Guide for the Use of Models and Simulations, September 1994.

Some M&S Capability Definitions

As mentioned earlier, the subcommittee found that there was no accepted taxonomy for M&S capabilities. Although creating a complete taxonomy was felt to be too large an effort for this study, the subcommittee did attempt to find authoritative definitions wherever possible.

Although in many cases, definitions could be found at the individual capability level, sometimes definitions were best left at the M&S capability category level, such as for the four levels of the military simulation pyramid.

The above table shows some definitions extracted from the M&S-Capabilities-to-Tools Map spreadsheet in the Excel workbook. The first two rows in the table show entries for which definitions could be found at the M&S capability level, in this case, for different types of cost modeling. The last two rows show entries for which definitions were left at the M&S capability category level, wherein the name of the specific M&S capability itself was considered as a sufficient modifier to the M&S capability category to explain the nature of the capability. As also evident from the above table, although it was sometimes possible to cite a definition verbatim from an authoritative source, it was often necessary to slightly modify the wording. In this case, the qualifiers “adapted from” or “derived from” were used to indicate that some modifications were made.



Some M&S Capability Definitions (2 of 2)

M&S Capability Name	M&S Capability Category	M&S Capability definition/description	Definition Source (reference citation - state if verbatim or adapted from; or defined here)
Virtual team training simulation	Mission training simulation	Virtual simulations involve real people operating simulated systems. Virtual team training simulations are virtual simulations that train two or more persons to achieve a common goal.	Adapted and expanded upon from the DoD M&S Glossary
Air drop mission simulation (Air Force)	Mission-level simulation	(Category-level definition) Simulation of the ability of a multi-platform force package to accomplish a specific mission objective, which might span a period of hours. Produce measures of effectiveness typically at the force package level rather than at the level of the individual platform and its weapon system.	Defense Systems Acquisition Management College, Acquisition Manager's Guide for the Use of Models and Simulations, September 1994.
Level-of-repair modeling	RAM modeling / simulation	Level of repair identifies not only the repair location, but also determines the extent of maintenance to be performed at organic, intermediate, and depot levels as well as the resources needed to support the repair process.	Adapted from: Proceedings of the IEEE 1988 National Aerospace and Electronics Conference: NAECON 1988 (Cat. No.88CH2596-5)
Supply chain modeling	RAM modeling / simulation	Models to support the analysis and improvement of the effectiveness of supply chain management and related supply chain improvement activities.	Defined here (JJB)
Live-Virtual-Constructive (LVC) simulation environments		An interacting set of simulations and supporting tools and resources, which includes live simulations, virtual simulations, and constructive simulations.	Defined here (JEC)

Some M&S Capability Definitions (continued)

The above table shows some additional M&S capabilities from the M&S-Capabilities-to-Tools Map spreadsheet in the Excel workbook. Several of these entries show the same verbatim or adapted uses of definitions from authoritative sources. However, somewhat surprisingly, there were some M&S capabilities, the names of which appear in rather common usage, for which subcommittee members could not find an authoritative source for their definitions. In these cases, individual members of the subcommittee took the action to construct such a definition for the purpose of this study. To maintain traceability of the definition, the phrase "defined here" was placed in the source column, along with the initials of the subcommittee member who constructed the definition.



Acquisition Activities and M&S Capabilities (1 of 5)

• Excerpt From Materiel Solution Analysis Phase

Acquisition Activity (Level 1)	Acquisition Activity (Level 2)	Acquisition Activity (Level 3)	Modeling / Simulation Capability
Conduct AoA	Characterize candidate materiel solutions	Identify key attributes and performance measures (differentiators)	
		Develop CONOPS/concepts of employment	Use-case modeling
		Identify Intel, Logistics, Information Support Needs/Constraints	Scenario definition modeling
		Identify key operational dependencies and inter-relationships	Mission-level simulation
	Perform operational effectiveness analysis	Develop appropriate scenarios and threats	Scenario definition modeling
		Determine mission tasks	
		Determine MOEs and MOPs for mission tasks	
		Determine analysis methodology	
		Select models and data	M&S catalogs and repositories
		Develop database	
		Conduct operational effectiveness analysis against selected MOEs and MOPs	Campaign-level simulation
		Perform sensitivity analyses	Mission-level simulation
		Validate with operators, stakeholders, and users	
	Perform initial cost analysis	Develop life cycle cost models	Life-cycle cost modeling
		Conduct cost vs. operational effectiveness analysis	Value modeling
	Perform risk analysis for each candidate materiel solution	Perform sensitivity analysis	
		Identify technical risks	
		Identify schedule risks	
		Identify cost risks	
	Synthesize operational, cost, and risk analyses results and rank candidate materiel solutions	Identify operational risks	
	Develop range of requirements to support development of initial KPPs		
	Document results in AoA Final Report		

Activities and M&S Capabilities for Materiel Solution Analysis

For the Materiel Solution Analysis Phase, the subcommittee had the benefit of a detailed breakdown of acquisition activities that was produced by the Development Planning Working Group (DPWG). The DPWG's work included the development of an Excel spreadsheet titled "Materiel Solution Analysis Activities and Descriptions" produced by a team led by Mr. Bill Riski in June 2012. The subcommittee has received permission to include the breakdown of activities in that Excel spreadsheet in its work. This has permitted a three-level hierarchical breakdown of acquisition activities in the Materiel Solution Analysis phase.

The above excerpt from the Activities-to-Capabilities Map spreadsheet in the subcommittee's Excel workbook shows the breakdown of activities for conducting an Analysis of Alternatives (AoA). In some cases, the activities are broken down only to the second level, but often are broken down to the third level. In some cases, the subcommittee did not think that an activity could be readily aided by any M&S capability, in which case the right-most column was left blank. The non-blank entries are actually represented by links in the spreadsheet to specific M&S capabilities or M&S capability categories in the M&S-Capabilities-to-Tools Map spreadsheet.



Acquisition Activities and M&S Capabilities (2 of 5)

• Excerpt from Technology Maturation and Risk Reduction Phase

Acquisition Activity (Level 1)	Acquisition Activity (Level 2)	Acquisition Activity (Level 3)	Modeling / Simulation Capability
	Development & technology risk reduction		Engineering-level simulation
			Virtual system simulation
			Mission-level simulation
	System integration		Engineering-level simulation
			Mission-level simulation
			Virtual system simulation
	Design		Engineering-level simulation
			Virtual system simulation
			Mechanical design modeling
			Software modeling
			Manufacturing process modeling/simulation
			Reliability modeling
			Maintenance simulation
			Survivability simulation
			Life-cycle cost modeling
			Engineering-level simulation
	Prototyping		Mission-level simulation
	Military utility assessment		Virtual system simulation
			Mission-level simulation
	Model environment and demonstrate technology		
	Interoperability & supportability analysis		Modeling of the natural environment
			Mission-level simulation
			Reliability modeling
			Maintenance simulation
			Survivability simulation
	Assess manufacturing risks		Life-cycle cost modeling
			Supply chain modeling
			Investment cost modeling
			Manufacturing process modeling/simulation

Activities and M&S Capabilities for Technology Maturation and Risk Reduction

For the Technology Maturation and Risk Reduction (formerly, Technology Development) phase (as well as most of the other phases of the Acquisition Life Cycle), the subcommittee did not have a detailed breakdown of acquisition activities. Instead, it relied predominantly upon the high-level description of activities in this phase, as embodied in the Defense Acquisition University (DAU) “wallchart” titled “Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System” of June 2010. For one activity (Update AoA), the subcommittee adapted the more detailed breakdown from the Materiel Solution Analysis phase. For the remainder, all activities from the DAU wallchart were placed at the second level of the breakdown, so that more detailed breakdowns might be added in the future.

The subcommittee considered it beyond the scope of its activities to construct a detailed breakdown of acquisition activities in the Technology Maturation and Risk Reduction phase (or succeeding phases). The subcommittee believes this would be a worthwhile activity for a broader systems engineering study, rather than an M&S-specific activity.



Acquisition Activities and M&S Capabilities (3 of 5)

• Excerpt From Engineering and Manufacturing Development Phase

Acquisition Activity (Level 1)	Acquisition Activity (Level 2)	Acquisition Activity (Level 3)	Modeling / Simulation Capability
	Develop affordable and executable manufacturing process		Manufacturing process modeling/simulation
	Ensure operational supportability		Operational availability modeling Supply chain modeling Logistics simulation
	Reduce logistics footprint		Logistics simulation
	Human Systems Integration		Operator training simulation Mission training simulation Human factors modeling Human-system integration simulation Engagement-level simulation
	Design for producibility		Virtual system simulation Manufacturing process modeling/simulation Engineering-level simulation
	Demonstrate system integration		Constructive battle simulation
	Demonstrate system interoperability		Virtual system simulation Constructive battle simulation
	System threat assessment		Virtual system simulation Engagement-level simulation Constructive battle simulation
	Material operational availability assessment		Virtual system simulation
	Prototyping		Operational availability modeling Engineering-level simulation Constructive battle simulation
	Integrated T&E		Virtual system simulation Engineering-level simulation Virtual system simulation

Activities and M&S Capabilities for Engineering and Manufacturing Development

For the Engineering and Manufacturing Development (EMD) phase, the subcommittee also relied on the DAU wallchart for the breakdown of acquisition activities. So, for this phase, all acquisition activities were listed at the second level of the breakdown in the subcommittee's Excel spreadsheet for this phase.

The subcommittee found that a large majority of the acquisition activities in the EMD phase can be supported by M&S capabilities. Although some activities, such as cost estimation, also occur in other phases, the EMD phase is characterized by more detailed engineering activities than prior phases. Although the structure of the spreadsheet is not conducive to revealing it, the fact engineering-level simulation appears often as a supporting M&S capability category implies that a significant number of M&S tools can be employed in this phase, because of the significant number of technologies that might be involved in any specific system.



Acquisition Activities and M&S Capabilities (4 of 5)

• Excerpt From Production and Deployment Phase

Acquisition Activity (Level 1)	Acquisition Activity (Level 2)	Acquisition Activity (Level 3)	Modeling / Simulation Capability
	Manufacturing development		
	Interdependency & interoperability summary		
	Risk management		
	Technology maturity assessment		Engagement-level simulation
	Industrial/manufacturing readiness assessment		
	CBRN survivability analysis		
	Human Systems Integration		Operator training simulation
			Mission training simulation
			Human factors modeling
			Human-system integration simulation
			Virtual system simulation
	Military equipment valuation		
	Corrosion prevention & control		
	Support & cost baseline		Life-cycle cost modeling
			Operations and support (O&S) cost modeling
			Investment cost modeling
	Supply chain management		Supply chain modeling
			Logistics simulation
	Refine life-cycle sustainment plan		Supply chain modeling
			Logistics simulation
	Production qualification testing		
	TOT&E		Constructive battle simulation
			Engagement-level simulation
			Engineering-level simulation
			Virtual system simulation
	Joint interoperability certification/testing		Constructive battle simulation
			Virtual system simulation
	Modify HW/SW Specifications and configurations		
	Verify and validate production configuration		Engineering-level simulation

Activities and M&S Capabilities for Production and Deployment

For the Production and Deployment phase, the subcommittee also relied on the DAU wallchart for the breakdown of acquisition activities. So, for this phase, all acquisition activities were listed at the second level of the breakdown in the subcommittee's Excel spreadsheet for this phase.

During this phase, activities that can be aided by M&S capabilities begin to get more focused on test and evaluation (T&E) and planning for long-term support of the system. Many testing activities can be supported by real-time simulations where it is too expensive or unsafe to employ real assets. Sustainment-related M&S capabilities also get more emphasis.



Acquisition Activities and M&S Capabilities (5 of 5)

• Excerpt From Operations and Support Phase

Acquisition Activity (Level 1)	Acquisition Activity (Level 2)	Acquisition Activity (Level 3)	Modeling / Simulation Capability
	Post-production software support		Software modeling
	Supply chain management		Supply chain modeling
	Monitor performance & adjust product support		Operational availability modeling
			Product support optimization modeling
	Training	Operator training	Virtual system simulation
			System/range instrumentation
			Task-oriented constructive simulation
			Game-based simulation
		Mission Training	Live-Virtual-Constructive (LVC) simulation environments
			Constructive battle simulation
			Virtual team training simulation
			Game-based simulation
		Maintenance training	Hardware-in-the-loop simulation
			Virtual system simulation
	Revalidate BCA		
	Refine life-cycle sustainment plan		Life-cycle cost modeling
	Supportability assessments	Level-of-repair analysis	Level-of-repair modeling
		Support optimization	Product support optimization modeling
		Obsolescence analysis	Obsolescence modeling
	Disposal planning	Environmental analysis	
		Hazardous material analysis	
		Recycling analysis	
		Business case / business model analysis	
			Disposal cost modeling
	Validate failures & determine root causes		
	Determine system risk / hazard severity		

Activities and M&S Capabilities for Operations and Support

For the Operations and Support phase, the subcommittee started with the DAU wallchart for the breakdown of acquisition activities, listing those activities at the second level of the breakdown in the subcommittee's Excel spreadsheet for this phase. However, the subcommittee was able to break down these activities to another level of detail, as shown in the excerpt above.

In this phase, one sees the beginning of training activities, which are often considered to be separate from the acquisition process itself, which are supported by some M&S capabilities that receive less emphasis in earlier phases, such as games-based simulations. Disposal cost modeling also begins to have some emphasis during this phase.



Excerpt From M&S-Capabilities-to-Tools Map (1 of 2)

M&S Capability Name	M&S Capability Category	Example tools						
Disposal cost modeling	Cost modeling	SEER-H	TruePlanning	SEER-MFG	ProModel Suite			
Life-cycle cost modeling	Cost modeling	ProModel - Portfolio Simulator	SEER-H	SEER-SEM	SEER-IT	TruePlanning	Price	PRICE
Operations and support (O&S) cost modeling	Cost modeling	OSCAM	COHORT	OSMIS	SEER-H	SEER-SEM	SEER-IT	TruePlanning
Investment cost modeling	Cost modeling	SEER-H	TruePlanning	SEER-MFG	ProModel Suite			
Fixed wing aircraft system simulation	Engagement-level simulation	Brawler	ESAMS	RADGUNS	MOSAIC	AFNES		
Land vehicular system simulation	Engagement-level simulation	OneSAF	JANUS					
Missile defense system simulation	Engagement-level simulation	EADSIM	AFNES	WILMA				
Missile system simulation	Engagement-level simulation	ESAMS	MOSAIC	WILMA				
Rotary wing aircraft system simulation	Engagement-level simulation	OneSAF	ATCOM					
Electrical printed circuit design simulation	Engineering-level simulation	PSpice	Zuken	Lattice	Expedition			
Electromagnetic propagation modeling	Engineering-level simulation	TEMPER	ICEPIC					
Structural dynamics simulation	Engineering-level simulation	DYNA-3D	LS-DYNA	SolidWorks				
Structural mechanics modeling	Engineering-level simulation	NASTRAN	SolidWorks	VAPO				
Thermal analysis simulation	Engineering-level simulation	FLOTHERM	FLOPACK	Saber				

Example M&S Tools

As discussed earlier in this report, the subcommittee decided that its final product would cite only “example” M&S tools, based on the personal knowledge of the subcommittee members, because it was difficult to determine authoritatively what M&S tools are “prevalent” (the terminology used in the subcommittee’s charter). The above table, which is an excerpt from the M&S-Capabilities-to-Tools Map spreadsheet, shows some example M&S tools for a number of M&S capabilities. Definitions of acronyms are given in the M&S Tools List spreadsheet.

This table illustrates a number of M&S capabilities in the engagement-level simulation and engineering-level simulation categories. Although there are occasional occurrences of the same M&S tool for multiple capabilities, it is also evident that, at least in the capabilities shown, different M&S tools are applicable to engagement-level simulations for different types of systems, and to engineering-level simulations for different technologies. There was no attempt to make the number of example M&S tools listed consistent across the various M&S capabilities. There was also no attempt to list every M&S tool that applies to each M&S capability. The M&S capability comprising catalogs and repositories, such as the DoD M&S Catalog, can be accessed to obtain information on a much larger number of M&S tools (literally in the thousands), and there was no intent to duplicate this capability in this study.



Excerpt From M&S-Capabilities-to-Tools Map (2 of 2)

M&S Capability Name	M&S Capability Category	Example tools			
Anti-submarine warfare mission simulation (Navy)	Mission-level simulation	BFEM	NSS		
Anti-surface warfare mission simulation (Navy)	Mission-level simulation	EADSIM			
Command and control mission simulation (Air Force)	Mission-level simulation	JIMM	Suppressor	EADSIM	AFNES
Counterair mission simulation (Air Force)	Mission-level simulation	JIMM	Suppressor	EADSIM	AFNES
Counterland mission simulation (Air Force)	Mission-level simulation	JIMM	Suppressor	AFNES	
Countersea mission simulation (Air Force)	Mission-level simulation	JIMM	Suppressor	AFNES	
Electronic combat mission simulation (Navy and Air Force)	Mission-level simulation	JIMM	Suppressor	AFNES	IMOM
Fires mission simulation (Army)	Mission-level simulation	FireSim	AFNES		
Level-of-repair modeling	RAM modeling / simulation	COMPASS	LORA 9.32		
Logistics simulation	RAM modeling / simulation	OPUS10	SIMLOX	ProModel Suite	
Operational availability modeling	RAM modeling / simulation	TLCM-AT	OPUS10	SIMLOX	ASOAR
Campaign-level simulation	Campaign-level simulation	STORM	JAS	SEAS	CTEM

The current version of the Excel workbook contains 103 M&S capabilities, most of which are contained in 11 M&S capability categories, and 148 example M&S tools. Tool acronyms are defined in the M&S Tools List spreadsheet.

Example M&S Tools (continued)

The above table provides some additional examples of M&S tools used for a different set of M&S capabilities than shown in the previous table. In this case, for mission-level simulation within related mission areas within the purview of the same Service, one can see that often the same example M&S tools were cited.

In this initial version of the Excel workbook, there are 103 M&S capabilities identified, and 148 example M&S tools.



Summary

- **The associated Excel workbook will be maintained as a “living document”**
 - Available on the NDIA SE M&S Committee web site
 - Suggested changes and additions should be submitted to the NDIA SE M&S Committee leadership
 - Updates will be posted periodically (most likely annually)
- **The study developed a fairly “level” set of M&S capability descriptions, but a complete taxonomy of “M&S Capabilities” is remains a beneficial goal**
 - Too large an effort for a small number of volunteers
 - A well-defined, resourced effort would be needed

Summary

This report has presented the results of a study undertaken over the past two years by a volunteer subcommittee of the M&S Committee of the NDIA Systems Engineering Division. Unlike many studies, the primary product of the study is not simply a final text report, but the initial version of an Excel workbook that can be updated, as desired by the systems engineering M&S community of interest, so that it becomes a living document. The intent is to post this spreadsheet along with this report on the M&S Committee’s web site, so that it can be downloaded, utilized, and updated as needed. In order to provide configuration management, the M&S Committee’s leadership will act as the focal point to receive suggested updates, and to post appropriate updates periodically, perhaps on an annual basis.

Although the subcommittee developed what it believes to be a fairly level set of M&S capability descriptions, it is believed that development of a complete taxonomy of M&S Capabilities would be beneficial. However, to do so in an authoritative way that gives even treatment to all the areas of modeling and simulation used in systems engineering is too large an effort for a small number of volunteers. A larger DoD-resourced effort with a well-defined set of requirements is felt to be needed to accomplish this.