

# **Integration of Modeling and Simulation Into the Test and Evaluation Process**

Michael J. Leite, PE  
Modeling and Simulation Project Manager  
SAIC

## **ABSTRACT**

As systems become more complex and cover larger mission areas, the utilization of modeling and simulation (M&S) to support the test and evaluation (T&E) of those systems becomes essential to the accomplishment of the test objectives. This paper examines how M&S employed to support design and development can be extended to support the accomplishment of developmental and operational testing (DT & OT). Through effective management of M&S activities, their results can support test objectives and streamline the conduct of DT & OT and facilitate the identification of deficiencies at the earliest stages in the acquisition cycle when corrections are least costly. The paper will also show that modeling and simulation as well as test and evaluation are integral parts of the System Engineering Process.

## **INTRODUCTION**

Regardless of the system or process involved, the development and acquisition of a system is based on the identification of requirements and the definition of the criteria and metrics by which the accomplishment of those requirements may be determined. The end-product is defined by the drawings and specifications provided to the builder; they identify what is to be produced and what is acceptable. The T&E process takes the identified criteria and metrics and determines the points in the fabrication cycle at which the tests are to be conducted to assure the acceptability of the finished product. This applies to any product—hardware or software.

Simultaneously, the designer and fabricator are using modeling and simulation (M&S) to refine their requirements and allocate functions to system elements. And, the technical staff is using M&S to refine and execute the design. In many cases, M&S is used in trade studies to determine the acceptance criteria and metrics for the finished product.

Historically, the testing community has lacked confidence in M&S for testing, preferring to test the “real thing.” Lax requirements for the verification, validation and accreditation (VV&A) of models and simulations contributed to the mistrust of M&S.

Presently, many systems are simply too large or costly to be tested using the finished product. In many cases, an entire theater of operation, including friendly, hostile and neutral forces, must be provided for the complete system test. In other cases, weapon

effects are too extensive and complex to lend themselves to field testing. The system itself may be too costly to be tested destructively. Finally, deferring end-to-end testing of a system until delivery of a prototype forfeits the opportunity to identify and correct flaws during development, when the cost of correction is much lower. For these and similar cases, modeling and simulation can “fill in the blanks” and allow the tester to assess the system’s performance.

## THE REQUIREMENTS PROCESS

The generation of requirements marks the start of a system development. A well-defined performance requirement includes a *performance*, a *criterion* that determines its attainment and a *metric* by which the criterion may be assessed. For example:

The machine will produce cap screws conforming to the dimensions for ANSI/ASME Class 2A threads [*PERFORMANCE*]  
at a production rate of 10,000 per hour [*CRITERION*]  
with a defect rate of not more than one per 1,000 units [*CRITERION*]  
as measured by an opto-electronic counter and with dimensions being verified by automated high-speed photo imaging. [*METRIC*]

The requirements for a product are set forth in its specification. A specification has two key sections. The first contains the requirements; the second establishes the verification or testability of each of the requirements. Every requirement must have an objective method by which conformance may be verified. The first step in the T&E process is the establishment of the testability of all of the requirements.

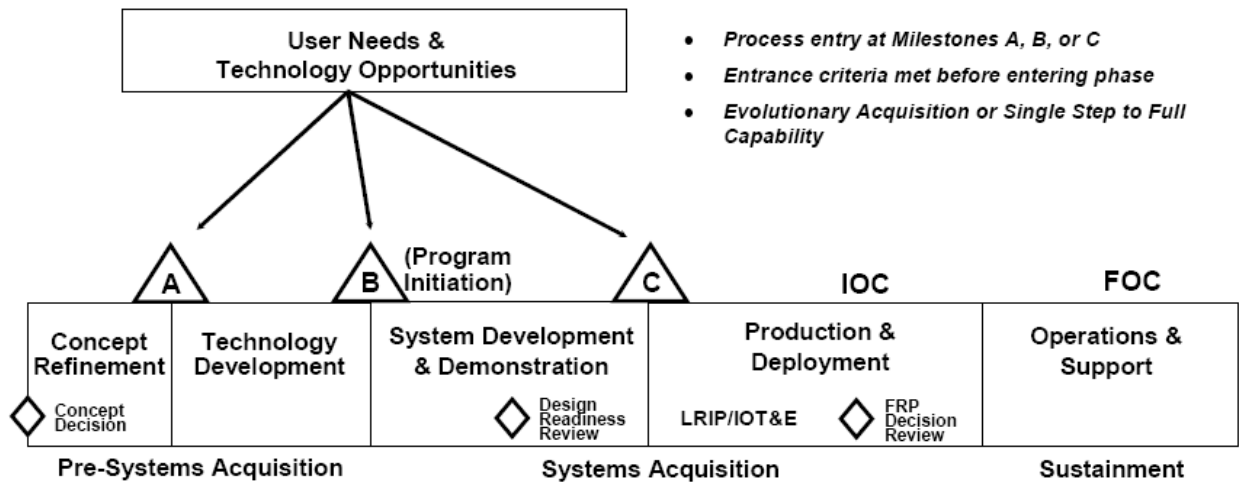
Within the U.S. Department of Defense, the process for developing requirements is set forth in the Joint Capabilities Integration and Development System (JCIDS).<sup>(1)(2)</sup> The JCIDS process identifies system level requirements in terms of the capabilities required to perform a mission or major task. The JCIDS Process is illustrated in Figure 1 below. JCIDS is also the start of the System Engineering (SE) Process.

Once the system-level requirements are established, they must be allocated to the various elements of the system. For complex systems this is accomplished by tiering the specifications in which each requirement is decomposed and allocated to a specific subsystem or element. In this process the verification is also decomposed such that the testability of the elements supports the verification of the assembled subsystems and ultimately the complete product. For large projects, the allocation and decomposition of requirements and their associated verification is best managed through the use of a computer program like the DOORS<sup>®</sup> software package by Telelogic [<http://www.telelogic.com/>]. The classification of specifications by their hierarchy within the system is described in MIL-STD-490A<sup>(3)</sup>. While the document has been

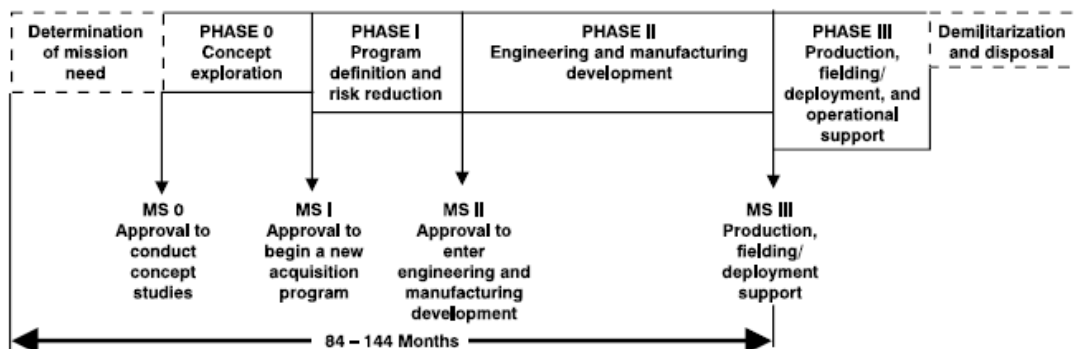


## THE ACQUISITION PROCESS

The current acquisition process<sup>(4)</sup> for the U.S. Department of Defense (DoD) is shown in Figure 2. It was streamlined from the process<sup>(5)</sup> shown in Figure 3. As a practical matter, approaches of both figures are addressed in by the revised process<sup>(6)</sup> that is shown in Figure 4 and incorporates the requirements development process and development spirals.



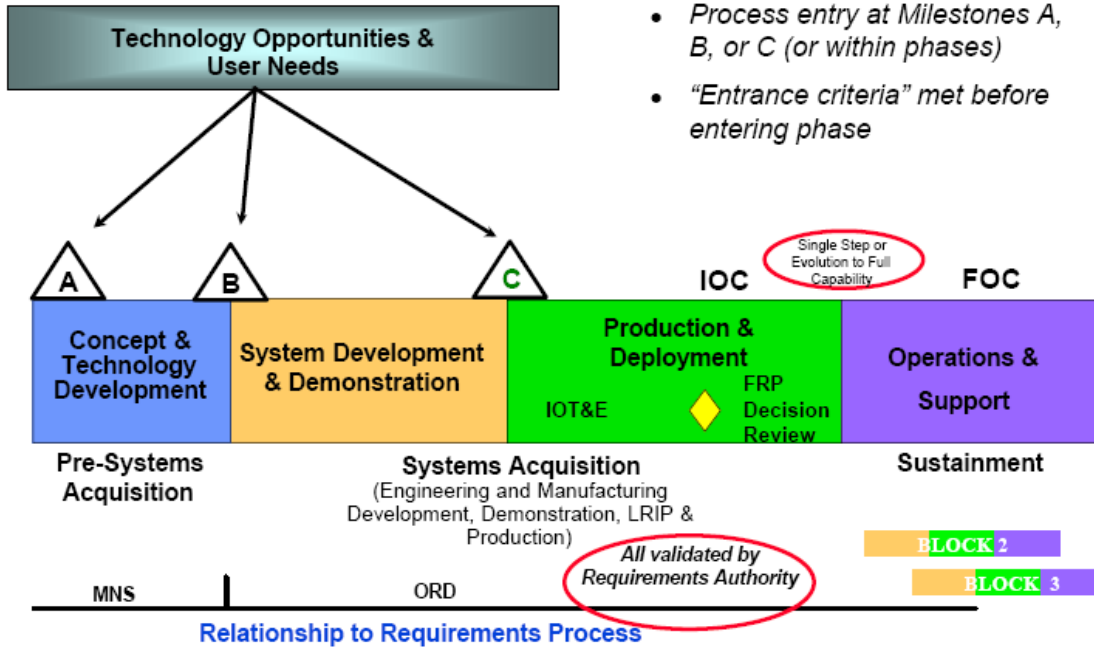
**Figure 2. The Defense Acquisition Management Process**



**Figure 3. The Former Defense Acquisition Management Process**

While there have been many efforts to streamline the process and shorten the overall cycle, the most critical element of the process is the definition of the required system performance requirements and the identification of the criteria and metrics by which the finished product will be measured. When new or advanced technologies are involved, the process of requirements definition is further complicated by the need to complete

development milestones to prove the technology before the production requirements can be established. M&S in this phase can help determine what is possible and support the allocation of performance requirements to the system elements, and it can identify risk items and suggest mitigation strategies.



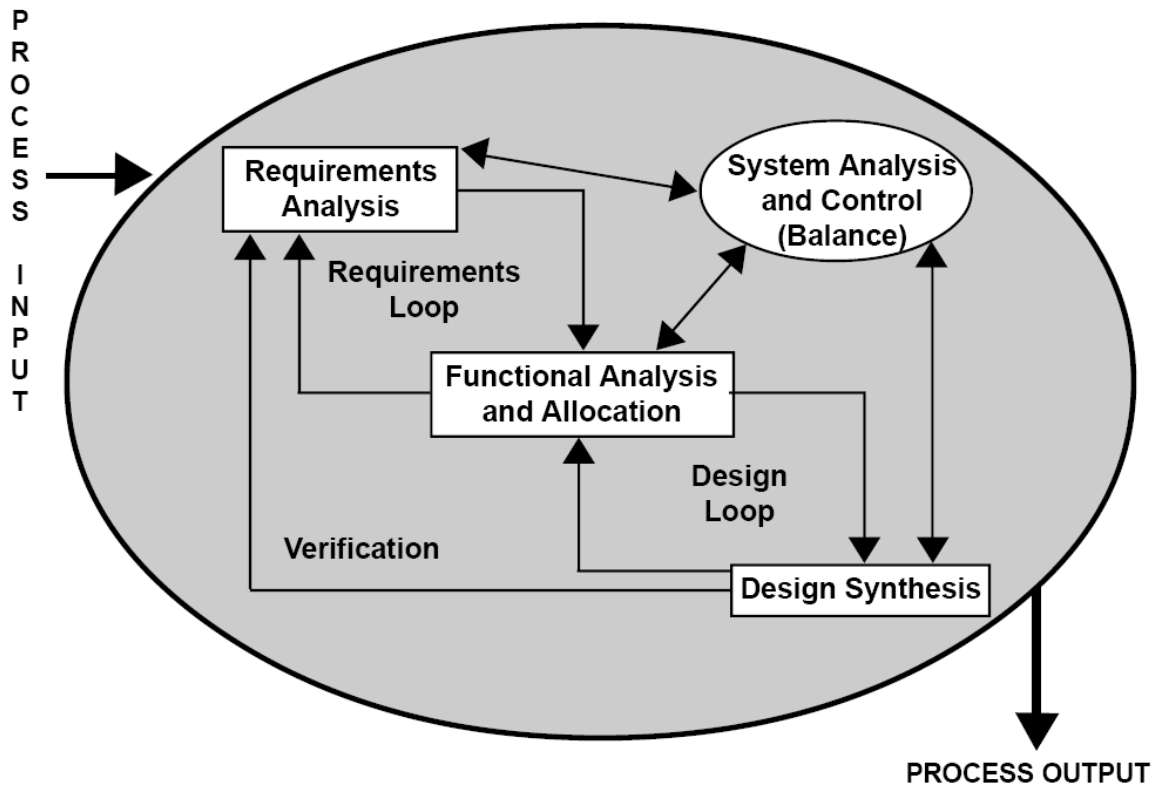
**Figure 4. Revised Acquisition Management Process**

## THE SYSTEM ENGINEERING PROCESS

The system engineering process is the glue that holds a project together. Once a requirement for a product or system has been identified and a program initiated, the first step is the establishment of a system engineering management plan (SEMP). The plan integrates all of the processes associated with the development and ties them to the phases and milestones of the acquisition process. It also identifies the interdependencies among the processes so that their individual plans are mutually supportive.

The general system engineering process<sup>(6)</sup> is shown in Figure 5. There are many management styles by which the process is applied. They depend on the type of acquisition and the style of the management team.

As will be seen in subsequent sections, modeling and simulation, along with test and evaluation, are linked to all aspects of the development process. Accordingly, their integration into the SEMP is critical to the successful employment of M&S to support the development and its T&E.



**Figure 5. The Systems Engineering Process**

## **THE TEST AND EVALUATION PROCESS**

The T&E process begins (or should begin) at the project’s inception and continues throughout the lifecycle of the project. At the outset, the testability must be defined for each requirement (performance or capability). In the design and development stage, Developmental Test and Evaluation (DT&E) establishes the performance baselines and test methodologies; it also establishes the feasibility of the design solutions. In production, T&E demonstrates the conformance to requirements. At delivery, Operational Test and Evaluation (OT&E) determines the suitability and capability of the completed system based on the stated requirements of the system. During, and at the end of, the life cycle, T&E determines whether the system should be modified or remain in service. For combat systems, Live Fire Test and Evaluation (LFT&E) establishes the survivability of the platform and assesses its ability to fight while damaged.

Figure 6 presents a generalized T&E process.<sup>(7)</sup> It corresponds to the “verification loop” in the System Engineering Process. As a supporting element of the System Engineering Process, the T&E Process is iterative. It starts with the design of the critical experiments conducted during the Concept and Technology Development Phase of the Acquisition Cycle and continues through the live fire and operational testing. For an efficient and effective T&E program, the results from each iteration must be carried forward to the

next. In that way there is traceability for the verification of requirements as they are aggregated from the component, module or element level up to the system level.

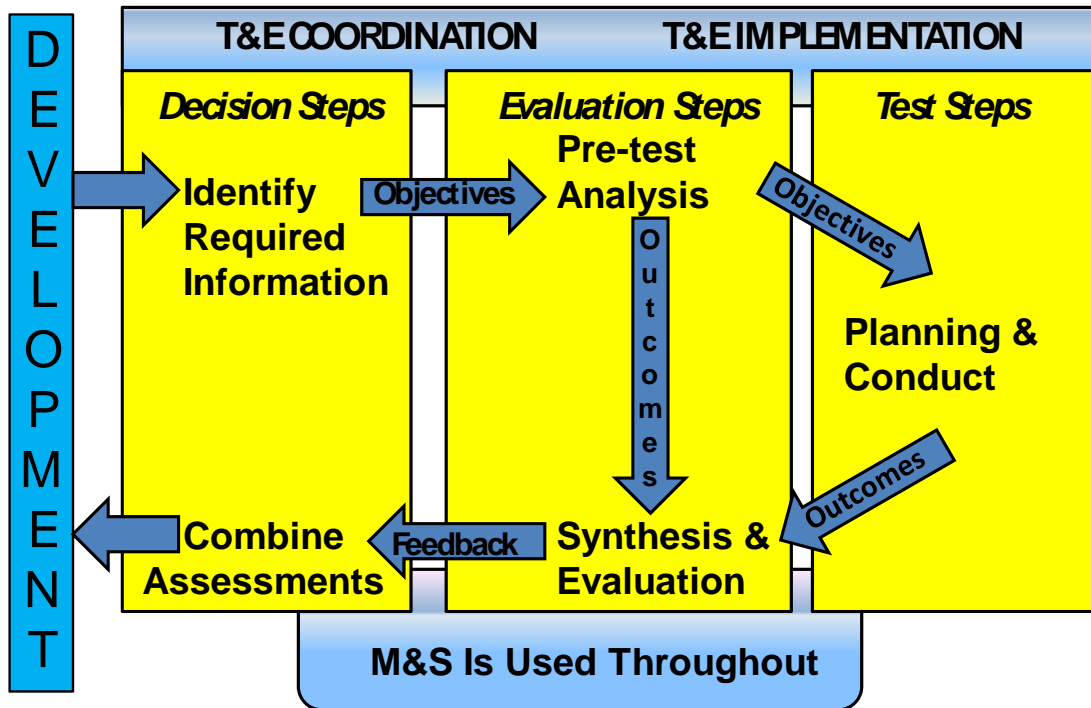


Figure 6. DoD Test and Evaluation Process

## M&S INTEGRATION ELEMENTS

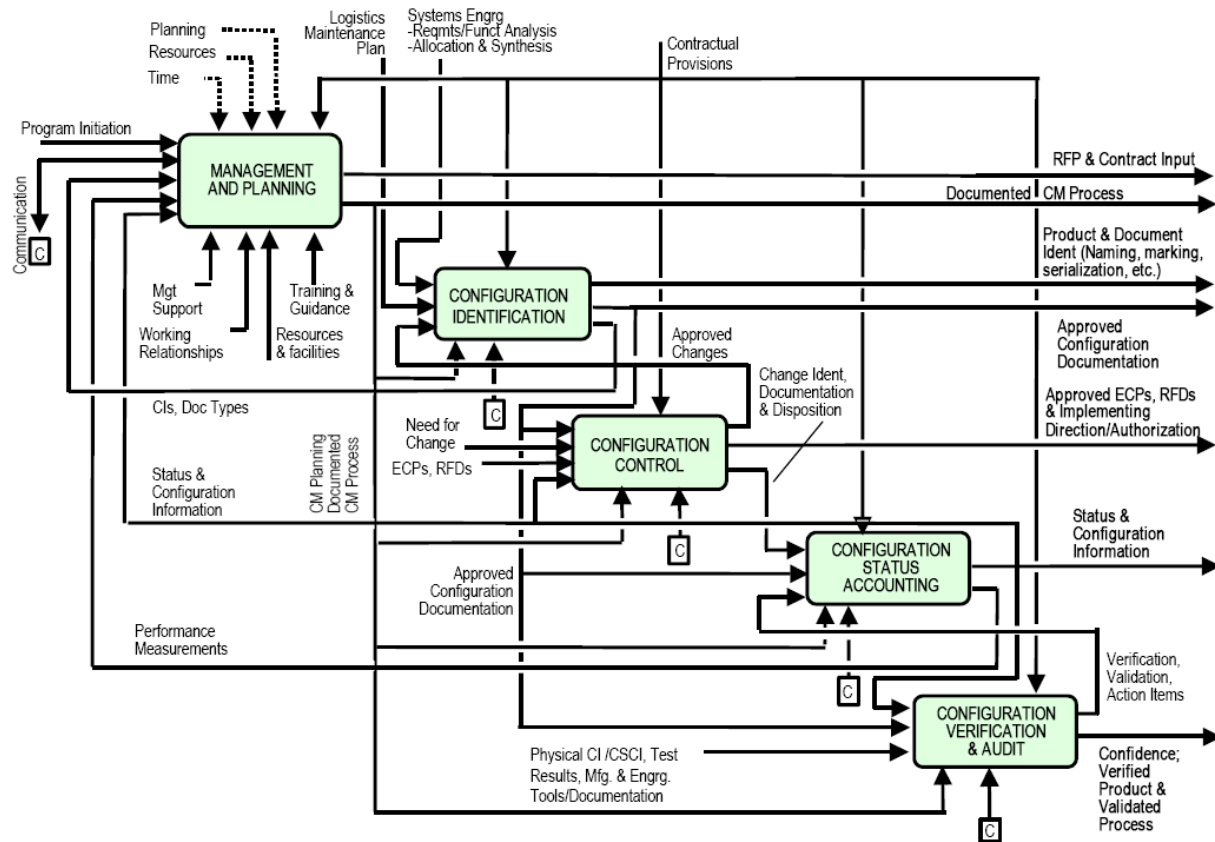
We have alluded to the uses of M&S to support the acquisition process above; however, for complex systems, M&S is used in all phases of design, development and T&E.

As with all applications, the adequacy of the M&S the tools is a prime concern. But, for modeling and simulation to properly support test and evaluation, there are two critical elements: *Configuration Management (CM)* and *Verification, Validation and Accreditation (VV&A)*.

### Configuration Management

M&S applications will morph over the course of the development as the requirements and design are refined and the system goes into production. In order for the M&S to be traceable to the requirements and their testability criteria, it is imperative that the configurations of all iterations of the models, simulations and their federations be

documented and traceable to the design decisions made as the development progresses. To this end, an active Configuration Management (CM) Program must be in place. In that way, the basis for the decisions is traceable and reproducible and can be used to support the VV&A process when the M&S results are used to support the T&E. A good reference for configuration management is MIL-STD-973.<sup>(8)</sup> Although the document has been cancelled and superseded by industry consensus standards, it remains an excellent source book for the practice of configuration management. Current guidance for the establishment and operation of CM programs is found in MIL-HDBK-61<sup>(9)</sup>. The process for the operation of the CM program is shown in Figure 7. CM can also provide the basis for the utilization of specific models and simulations in test events.



**Figure 7. The Configuration Management Process**

The key point is that, without CM, traceability and reproducibility are impossible and VV&A cannot be accomplished. For T&E, configuration management facilitates the reproducibility of test events and facilitates event reconstruction in the event of anomalies.

### **Verification, Validation and Accreditation**

The credibility of models and simulations is critical to their acceptance as part of the T&E process. Testers must have confidence that the M&S is providing a true or accurate

representation of the system’s performance, the test environment and the supporting systems. Guidelines have been developed and published for the documentation of VV&A, the conduct of the VV&A itself and the assessment of the maturity of the VV&A process.<sup>(10)</sup> Several are in the process of being adopted as Defense Standards and international consensus standards. The requirements for VV&A in the U.S. Department of Defense are found in DoD Instruction 5000.61, *DoD Modeling and Simulation (M&S) Verification, Validation and Accreditation (VV&A)*.

For M&S to support the test and evaluation program, VV&A activities must be in place from the outset of the program. This means that VV&A must be addressed in the SEMP and the appropriate accreditation agents identified at the outset. For M&S used in support of T&E, the accreditation determination must be made by the T&E organization based on verification and validation documentation supplied by the developer and Program Manager.

### M&S Selection and Employment

Modeling and simulation may be used in many ways to support test and evaluation. When integrated into the M&S effort for the design and development process, it can prove invaluable to the testers. Figure 8 shows the process for the development of new models and simulations.<sup>(10)</sup> It should be noted that the process for the adaptation of existing M&S tools is almost the same with the addition of some additional configuration management and verification and validation effort.

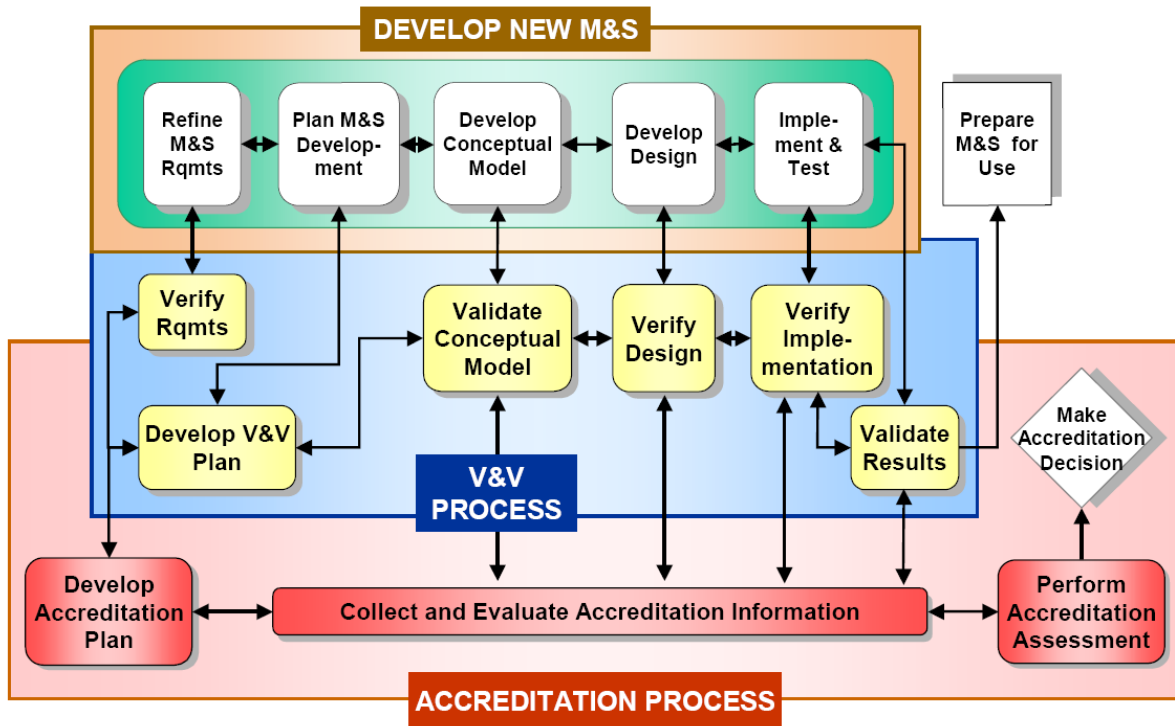


Figure 8. Development of Modeling and Simulation

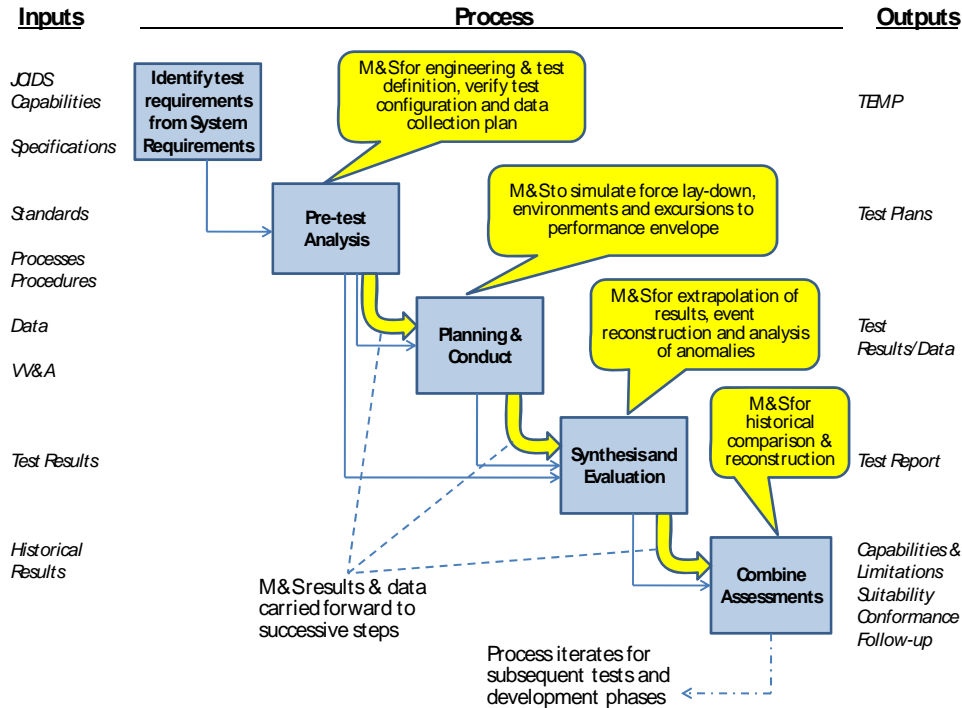
As with the development itself, the supporting M&S is also based on well-defined requirements. While much of the M&S used during the development is only loosely managed, the M&S selected to support the T&E effort must be closely controlled and managed. As the verification methods are identified for the requirements of the system under development, a set of requirements for the models and simulations that will support the T&E effort must also be developed. Those requirements and their testability will be based on the proposed application or test support. Some of the M&S applications for the support of T&E are:

- Assessment of system performance in environments that cannot be replicated in live (or field) tests
- Assessment of system performance with units or forces that cannot be made available in a field environment
- Extrapolation of small scale test results to the prediction of large system performance
- Validation of a proposed test configuration
- Verification of a data collection plan
- Validation of live test results
- Reconstruction and analysis of test anomalies

The selection of models and simulations must include a consideration of the internal processes by which they operate and the precision of their results. They may range from explicit simulations of the operational system which emulate all of the system processes to abstractions which use look-up tables based on calculated system parameters. They may be deterministic, producing discrete results, or they may be stochastic, producing results with a statistical confidence level. The selection of the M&S tools and techniques must be based on the test requirements; similarly, the number of runs necessary to establish the required confidence must also be calculated.

## **M&S IN TEST AND EVALUATION**

To this point, we have examined the piece parts associated with T&E, M&S and Systems Acquisition. The next step is to combine the elements into a consolidated effort from the perspective of the test and evaluation practitioner. To accomplish this we will take the iterative T&E process of Figure 6 and lay it out as the simplified flow process which is shown in Figure 9 below.



**Figure 9. Modeling and Simulation Integrated into the Test and Evaluation Process**

## A CASE STUDY

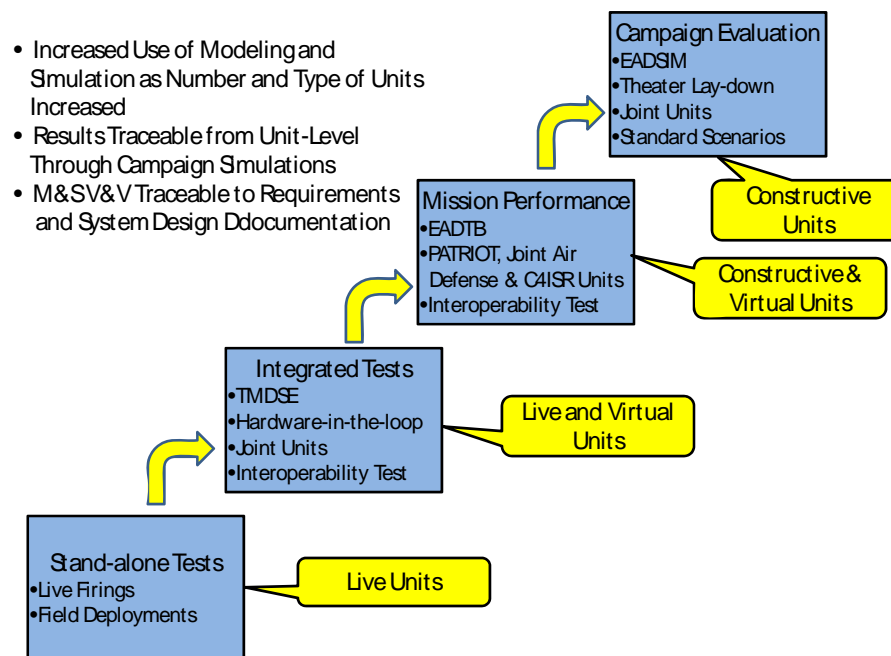
In order to move from the abstract to the real world, we will examine a case study involving the use of M&S to support a test and evaluation event.

The Initial Operational Test and Evaluation (IOT&E) of the Patriot PAC-3 System provides a good example of the use of M&S to support a major test event. It involved models and simulations ranging from the engineering and design realm to theater simulations. It also used Live, Virtual and Constructive forces simultaneously. The principal simulations were compliant with the standards for Distributed Interactive Simulations (DIS) and the High Level Architecture (HLA).

The M&S support for the IOT&E was conducted at three levels. The first was at the unit level and involved the simulation of the engagement in a battlefield or small theater environment. It involved the use of the then-Theater Missile Defense System Exerciser (TMDSE)<sup>(12)</sup>. [TMDSE was subsequently renamed the Missile Defense System Exerciser (MDSE)]. The TMDSE provided a platform that integrated Tactical Systems (like PATRIOT and AEGIS) in a simulated Link-16 environment with virtual and constructive assets (Command and Control (C2) and remote sensors, respectively). The principal limitation of TMDSE was that only small numbers of each type of unit could participate. While the underlying algorithms and the basic kill chain could be evaluated, it was not possible to assess conflicts among units of the same type or the interactions with the C2 functions in a multi-threat, multi-mission environment.

To accomplish the second level of M&S, the Extended Air Defense Test Bed (EADTB) simulation engine was used. It utilizes models of every battlefield element involved in the missile defense mission execution which are called Specific System Representations (SSRs). EADTB incorporates the explicit simulation of system and tactical data processor performance. Tactical communications were based on the simulation of a Link-16 net. The EADTB simulation represented a tactical lay-down of PATRIOT Battalion along with all of the Army and Joint assets employed in support of an engagement. Using the simulation it was possible to assess the performance of the PATRIOT System against the design raid parameters. Because EADTB stochastically dealt with the uncertainties of sensor, interceptor and system performance, multiple runs were conducted to establish the most probable results and the distribution of the simulation runs. The verification and validation effort was a key element of the use of EADTB to support the IOT&E. Once the software V&V was complete, the major efforts were the verification that the system representations were, in fact, explicit representations of the tactical programs and the verification of the performance of the Link-16 simulation.

The third element of the IOT&E was to demonstrate that the PATRIOT System could perform correctly in a full theater environment in which air and missile defense were only a part of the overall mission areas and forces involved. To accomplish this, the Extended Air Defense Simulation (EADSIM) was used. Because EADSIM uses look-up tables with stochastic methods, it runs much faster than EADTB and is thus able to incorporate a larger force lay-down.



**Figure 10. Progression of M&S Support to IOT&E Effort**

As shown in Figure 10, the IOT&E followed a progression incorporating a transition from engineering tests to hardware-in-the-loop tests, engagement simulations and, finally, theater simulations. For the test program to be successful, the results at each level had to be validated and shown to be traceable to the test results from the previous level of testing. The success of the IOT&E effort can also be traced to the participation of the test and evaluation community in the program from the outset.

Modeling and simulation provided the ability to test the PATRIOT System in ways that could not be replicated in the field. The reasons for this included cost, availability of forces to participate in the test event, and the lack of a range that could accommodate theater-level engagements. By scaling the tests from the engineering level to the theater level, it was possible to integrate the M&S directly with the test events and provide both validation and traceability of the results. The use of TMDSE and EADTB demonstrated the successful integration of live, virtual and constructive assets in a T&E environment.

While M&S can be invaluable in supporting Test and Evaluation, its limitations must also be recognized. Models and simulations can only perform within the limits of their underlying algorithms, and this limits the extent to which the “real world” can be represented and the reactions of the system tested. Key variables that cannot be completely represented are human performance under the stress of combat. This can result in delays which render the system ineffective or errors in judgment that can result in fratricide. As system automation increases and reaction time decreases, these factors will become ever more critical. A second area in which M&S capabilities are limited is operations conducted under degraded conditions; this includes degraded environments (weather, electromagnetic) and degraded equipment performance (sensors, communications, jamming). The limitations of M&S for the support of a test event should be identified as a part of the verification and validation process and should be noted in the accreditation of the M&E.

## **CONCLUSION**

Several conclusions may be drawn from the foregoing; they include:

1. The Test and Evaluation Process is part of the System Engineering Process. It commences with the initiation of the project and runs concurrently with all of the other project processes throughout the lifecycle of the project.
2. Modeling and Simulation can add value to the T&E process by providing:
  - Assessment in environments that cannot be replicated in live (or field) tests
  - Assessment with units or forces that cannot be made available
  - Extrapolation of small scale test results to system performance prediction
  - Validation of test configurations

- Verification of a data collection plans
- Validation of test results
- Reconstruction and analysis of test anomalies

3. The M&S limitations in the support of a test and evaluation event must be recognized and documented.

## REFERENCES AND BIBLIOGRAPHY

1. CJCSI 3170.01E, *Joint Capabilities Integration and Development System*, May 11, 2005
2. CJCSM 3170.01B, *Operation of the Joint Capabilities Integration and Development System*, May 11, 2005
3. MIL-STD-490A, Military Standard, Specification Practices, June 4, 1985, the document is cancelled but may be obtained from <http://www.assistdocs.com/> (Accessed September 6, 2007)
4. DoDI 5000.2, *Operation of the Defense Acquisition System*, May 12, 2003
5. Acquisition History Project Working Paper #3, *The Evolution of DoD Directive 5000.1, Acquisition Management Policy, 1971 to 2003*; Defense Acquisition History Project; U.S. Army Center for Military History, Ft. McNair, Washington, D.C.; Undated; Internet: <http://www.army.mil/cmh-pg/acquisition/> (Accessed August 7, 2007)
6. *Systems Engineering Fundamentals*; Defense Acquisition University Press, Ft. Belvoir, VA; January 2001
7. *Simulation Test and Evaluation Process (STEP) Guidelines*; Director Operational Test and Evaluation; December 4, 1997
8. MIL-STD-973, *Military Standard, Configuration Management*, April 17, 1992, the document is cancelled but may be obtained from <http://www.assistdocs.com/> (Accessed September 6, 2007)
9. MIL-HDBK-61, *Military Handbook, Configuration Management Guidance*, February 7, 2001, the current edition of this document [MIL-HDBK-61A(SE)] may be obtained from <http://www.assistdocs.com/> (Accessed September 7, 2007)
10. *VV&A Recommended Practices Guide (RPG)*; Defense Modeling and Simulation Office (DMSO) [now: Department of Defense Modeling and Simulation Coordination Office (DoD M&S CO)]; September 15, 2006; Internet: <http://vva.dmsomil/default.htm> (Accessed: September 4, 2007)
11. DoDI 5000.61, *DoD Modeling and Simulation (M&S) Verification, Validation and Accreditation (VV&A)*, May 13, 2003
12. Buxton, Bradley ; Cage, Max ; Munkres, Marilyn; Perry, David; *Interoperability Testing Using the Hardware-in-the-Loop Test Tool*; TRW Inc., Contractor to the Joint National Test Facility (JNTF), Colorado Springs, CO; June 24, 1999; available from the Defense Technical Information Center (DTIC); Accession Number ADA370545

## **AUTHOR BIOGRAPHY**

**MICHAEL LEITE** is a Modeling and Simulation Project Manager with Science Applications International Corporation where he provides SETA support to the Department of Defense Modeling and Simulation Coordination Office in Alexandria, VA. He is the Community Coordinator for the Test and Evaluation Community and is the Manager for Modeling and Simulation Namespace in the DoD Metadata Registry. A Registered Professional Engineer, he has previously supported modeling and simulation efforts at the Missile Defense Agency, DD-21 Gold Team, Cooperative Engagement Capability Program, and the Joint Theater Air and Missile Defense Organization. His Test and Evaluation experience includes Developmental Testing for the Naval Sea Systems Command and AEGIS Shipbuilding Program and Operational Testing for the PATRIOT Missile Program.

### **Acknowledgment:**

The author wishes to thank Dr. Terry Foreman of SAIC and Mr. David Duma, Principal Deputy Director, Operational Test and Evaluation, for their review and critique of this paper. Their inputs were invaluable in ensuring that the concepts were clearly and concisely communicated.

DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

Contract: GS09K99BHD0010; DoD Case 08-S-0203