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CAPABILITY MATURITY MODELS SUPPORT OF MODELING AND SIMULATION VERIFICATION, VALIDATION, AND ACCREDITATION

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ABSTRACT

Both government and industry are involved in the acquisition and development of modeling and simulation (M&S) products. The effectiveness and maturity of an organization's acquisition process directly affect the cost, schedule, and quality of the M&S products that are delivered to the user. When M&S program sponsors implement best practices throughout acquisition, critical verification, and validation (V&V) tasks can be conducted without inordinate cost. Department of Defense (DoD) Instruction 5000.61 on *M&S Verification, Validation, and Accreditation (VV&A)* directs that M&S systems used for acquisition decisions will be verified, validated, and accredited (DoDI 1996). However, many M&S users are attempting to implement VV&A processes for legacy M&S systems that lack documentation and are finding the costs unsupportable. The Carnegie Mellon University Software Engineering Institute (SEI) has described processes involved in implementing and measuring capability in software acquisition and development. These Capability Maturity Models ((CMM) and Capability Maturity Model are trademarks registered by Carnegie Mellon University) when applied together ensure that the acquisition process is in place before the software development process is implemented. This paper discusses how the use of these two CMMs can improve DoD's ability to develop M&S with the customer's need for VV&A in mind.

1 INTRODUCTION

We, as taxpayers, are spending altogether too much money on software. Some 76% of taxpayer's money spent for software is spent on software that is never delivered or never used, with only 2% spent on software systems that are usable upon delivery (Davis 1993). Many of our M&S efforts are very software-intensive.

The software crisis is not news. We've all read about it in professional journals. W. Wayt Gibbs' article in the September 1994 issue of Scientific American described the chronic state of the problem and the potential impact on the nation. Other experts like Fred Brooks, Barry Boehm, and Norm Johnson have addressed the problem many times. The statistics have been outlined and supported with case studies in The Standish Group's reports that cover both DoD and U.S. industry. No doubt many of us have witnessed some of the more than 30% of software development programs that failed. We are no longer shocked to hear that over half of software projects in the U.S. come in at about 180% over budget or that approximately only 16% of our software programs are successful (Standish 1995).

The software crisis has hardly abated in spite of the increasing availability and affordability of useful management and tracking tools. The root causes are strongly related: a decided preference for rapid production of 'code' or 'product', lack of sufficient accountability for process management, and an unfortunate lack of understanding that total ownership costs will be higher when documentation and configuration management are neglected. By the time a system has moved from 'new' to 'legacy' (sometimes without even seeing a real user), the management may have changed several times and funding cuts will have most likely been leveled at the life cycle support activities like traceability matrices, documentation and even configuration management.

For M&S programs, the shortsighted focus on product (read "code") has led to situation where the policy on M&S accreditation is not financially feasible. The documentation simply is not available to support the level of inspection needed to ascertain suitability of a model or simulation for a user's specific use. The cost of accreditation, at least for the first accreditation effort on a poorly documented system, may include almost prohibitive costs of reading code to determine what actually has been implemented before verification (of requirements) and validation (of representation) can even begin. Fortunately, there are exceptions where Program Managers have been cognizant

of Total Ownership Costs and have invested the requisite resources up front so that the system is useful to the customer, supportable over the life cycle and, in the case of M&S, documented well enough to support inspection for accreditation.

This inspection process is called V&V and amounts to the collection and maintenance of evidence that the system implements the requirements correctly and that the representations of the real world are as designed or as requested by the user. A properly-managed M&S system will be developed and maintained with the understanding by all involved that the product, like most products in the commercial marketplace, must be dependable, maintainable, understandable and useful. Good development, documentation, maintenance and management practices for software result in systems that can provide greater return on investment and can be evaluated for suitability without the exorbitant expense of re-engineering. Until program managers understand and implement good software development and management practices, M&S will continue to pose serious problems for users because credibility will be difficult to establish. Given the increasing reliance on M&S even in areas of operational testing, it is not sufficient to just mandate VV&A prior to use of M&S; we must make it possible to "conduct" VV&A. All new efforts in software development for M&S should be based on sound software engineering practices that make the product useful, maintainable, and well-documented. The CMM represents one widely used framework for appraising and improving the software development and management practices within an organization or project.

The CMMs examined in this paper provide software acquisition and development organizations with guidance on how to gain control of their processes for acquiring, developing and maintaining software and how to mature those processes even more. The CMM concept was first developed at Carnegie Mellon University's SEI. It is one of the most common methodologies used in industry today. Additionally, it is becoming commonplace to demand an independent rating on CMM level for each company competing for a contract award involving software.

2 BACKGROUND

In our world of software intensive systems, successful acquisition means obtaining quality software on schedule and within budget. DoD policy requires that software systems are designed and developed using disciplined software engineering principles (DoD 1999). A synergistic policy mandates that all M&S used within DoD be verified, validated, and accredited for the intended use(s) (DoDI 1996).

2.1 USD(AT&L) Policy Goal - CMM Level 3

The Under Secretary of Defense for Acquisition, Technology and Logistics (USD(AT&L)), the Honorable Jacques S. Gansler, directed in October 1999 that each contractor performing software development or upgrade(s) for use in Acquisition Category (ACAT) I programs undergo a software capability evaluation to determine the maturity of its software processes as a technical requirement for contract (Gansler 1999). Dr. Gansler's goal is for software developers to be in full compliance equivalent to the SEI Capability Maturity Model for Software (SW-CMM) Level 3. In March 2000, the Naval Air Systems Command (NAVAIR), expanded the scope with an interim policy applying the SW-CMM Level 3 requirement to all ACAT programs (I, II, III, and IV) within NAVAIR and the Naval Aviation Program Executive Offices (NAVAIR 2000).

At Level 3, the software engineering and management processes for developing and maintaining software are documented, standardized and integrated across the organization. Logicon Information Systems and Services (LISS) is one example of an organization that has been independently evaluated to receive a SW-CMM Level 3 rating as part of the government contract award process. LISS is one of three Logicon business units to be evaluated by external evaluators as a Level 3-software provider (Kresa 2000). This Level 3 evaluation provides an independent confirmation of LISS' sound processes for developing robust, high quality software. To ensure those mature processes are maintained Logicon instituted a system of internal assessments in which other business units periodically reassess LISS maturity.

2.2 Effect of CMM Level 3 Policies on M&S

The acquisition of M&S designed, developed, and used in support of any covered program comes under these policies. The use of mature processes can reduce the effort and cost allocated to V&V. Mature processes ensure that verification is conducted and that the products of software development can support validation. Accreditation decisions can be supported by a review of the documentation and a comparison against user's specific requirements and acceptability criteria.

3 SOFTWARE ENGINEERING INSTITUTE

To advance the practice of software engineering, the OUSD(AT&L) sponsors the Software Engineering Institute operated by Carnegie Mellon University. The SEI was established in December 1984 as a federally funded research and development center (SEI 2000).

The SEI mission is to advance software engineering practices that improve the quality of software-intensive systems so that DoD can acquire and sustain these systems with predictable and improved cost, schedule, and quality.

3.1 SEI Capability Maturity Models

The SEI CMMs were developed to help organizations to improve their software engineering management practices. The CMMs provide benchmarks that can be used by evaluators to grade the ability of an acquisition or programming organization to produce reliable, maintainable software that meets its customers' needs. The CMM uses a five-level scale, ranging from Chaos (Level 1) to the paragon of good practices at Level 5.

The Software Acquisition Capability Maturity Model (SA-CMM) is a model for improving an organization's software acquisition processes. The DoD is a major acquirer of software intensive systems and M&S used to support decision-makers and Program Managers who are acquiring M&S, and need to develop mature software acquisition processes.

The SW-CMM is a de facto standard used to judge the maturity of an organization's software processes and to identify what is required to mature of those processes. Organizations use the SW-CMM to determine their ability to develop and maintain software and as a guide to improve their software processes.

3.2 Software Capability Evaluation

The CMM establishes a frame of reference for performing software capability evaluations (SCEs). An SCE evaluates the management maturity level of an organization's software process to gain insight into its process capability Additionally, an SCE can identify risks associated with a project or contract for acquiring and building high-quality, dependable software on schedule and within budget. The findings from a SCE may be used to define, and potentially reduce, the risks in awarding a contract. Evaluations are also performed on existing contracts to monitor an organization's process performance and improvement.

The Deputy Under Secretary of Defense for Science and Technology (DUSD(S&T)), Dr. Delores M. Etter is responsible for acquisition software oversight, along with management oversight for the SEI. She is also responsible for defining SW-CMM Level 3 equivalence requirements for approved SCE tools to support policy (Etter 1999). Dr. Etter's Director for Software Intensive Systems, Dr. Jack Ferguson, is spearheading the effort to identify and evaluate candidate SCE tools. Two examples of current evaluation tools approved for use include the SEI Software Capability Evaluation and the Software Development Capability Evaluation created by the Air Force Materiel Command.

The U. S. Navy Commander Operational Test and Evaluation Force offers two methods to evaluate the software development process, which are described in COMOPTEVFORINST 5235.1A, *Software Development Appraisal Methodology* (DoN 1996). The Software Development Process Review (SDPR) is a simple, informal review to identify potential program risks early on. The Quick-Look (QL) is the more structured software appraisal. The QL is a comprehensive program review conducted after significant risks have been identified by the SDPR. The QL requires a 4- to 5-day documentation review and interview session. The findings provide the program manager and the operational test community with identified risks so that a risk mitigation plan can be instituted early in the development life cycle.

4 M&S ACQUISITION AND DEVELOPMENT

4.1 Definitions and Concepts

Clear communication demands a mutual understanding to the terms used to present the concepts under discussion.

Software is defined in the Department of the Navy as the detailed, complete, and unambiguous set of instructions embedded in a system or subsystem's computer hardware that enables the weapon, combat or support system to carry out its intended function or functions. The acquisition of software involves the definition and allocation of system requirements, an analysis of developmental concepts and alternative allocations, the definition of intra- and inter-module interfaces, and development of support documentation and systems. (DoN 2000).

Modeling and Simulation, a specialized subset of software, is a detailed, complete, and unambiguous set of requirements implemented as a computer application that models or simulates a weapon, combat or support system's intended function or functions. The acquisition of M&S involves the definition and allocation of requirements, an analysis of developmental concepts and alternative allocations, the definition of interfaces, and development of support documentation.

Verification is the process of determining that a model or simulation implementation represents the developer's conceptual description and specifications with sufficient accuracy. Verified means that the model executes its functions correctly, without consideration for whether its algorithms provide the required accuracy or capabilities.

Validation is the process of determining the degree to which a model or simulation is an accurate representation of the real world from the perspective of the intended uses of the model. Validated means that the model provides sufficiently accurate results and generates sufficiently correct answers within its stated limitations.

Accreditation is the process for determining whether or not a model or simulation is acceptable for use for a

specific purpose. This process ensures that the model or simulation produces realistic, sufficiently credible measurements of performance or specifically identifies the limitations on the use of data and analysis produced.

4.2 M&S Development Products

A modified version of the M&S development process is depicted in Figure 1. This process was adapted from the simplified version of the modeling process presented by Sargent (1999). There are four major products of the M&S development process: a requirements specification, conceptual model, the M&S application and, of course, all the associated documentation.

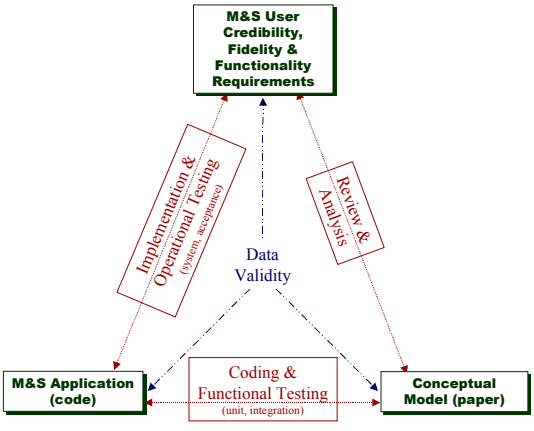

Figure 1: Modified M&S Development Process

M&S development is initiated with *Requirements* definition. Requirements represent the user's real-world operational needs, in terms of functionality, fidelity, and credibility. The verification of functionality requirements and validation of the M&S representations of the "real world" measure M&S credibility. Formal accreditation for use in a specific application is a determination that sufficient V&V has been performed and documented to ascertain that the M&S will meet the user requirements and acceptability criteria. The V&V steps required to support an accreditation decision can be planned only when the specific requirements are understood, and this will often be an iterative process. Verification cannot be conducted without a firm understanding of the requirement. Similarly, validation cannot be conducted without a firm understanding of the user's need for resolution and accuracy. With detailed requirements established and acceptability criteria determined, it is possible to tailor V&V to meet the acceptability criteria while managing cost, schedule, and performance. A conceptual model is a key element in the process of identifying and prioritizing V&V efforts.

The *Conceptual Model* describes how the M&S system will meet the requirements and how the "real world" is represented, including key algorithms and data and their sources. The conceptual model thus serves as a bridge between the defined requirements and the M&S design. The conceptual model should include text, diagrams and often equations to describe underlying assumptions, constraints, limitations, algorithms, and, where necessary, architecture. Development of the conceptual model is an iterative process of review, analysis, and modeling between the developer and the intended user. As functional or fidelity requirements are not or cannot be met, the requirements and/or the conceptual model are reexamined and modified if required. This refinement is inevitable in most programs because the initial intent of the M&S may evolve or the program may suffer funding cuts that result in reduced functionality or revised implementation. The conceptual model should also describe the planned use of and source of data. The intricate relationship between a simulation and the data that it requires has been recognized and the data is no longer considered separately. (DoN 1999).

The *M&S Application* is the conceptual model as implemented in code and possibly including hardware-in-the-loop. Software V&V are conducted during the software development process as well as during maintenance and enhancement. Software verification confirms that the each step in the development process correctly implements what was specified in the previous step and that functional requirements have been fulfilled. Software validation determines that a software product meets the design requirements, including fidelity, resolution, and accuracy requirements. M&S V&V are affordable if planned and performed in concert with software design, development and V&V testing.

Data Validity ensures that the data, which is necessary for formulating requirements, documenting the conceptual model, validating the M&S application, and then conducting experiments, are adequate and correct (Sargent 1999).

4.3 M&S VV&A

Table 1 briefly reviews basic principles for the management of VV&A (adapted from Balci 1998) and applicable to the M&S development process.

Table 1: Management Principles for VV&A

1	A well-formulated problem is essential to the acceptability of M&S results (accreditation).
2	Requirements must be specified in clear, unambiguous terms. Credibility is judged with respect to these requirements.
3	VV&A must be planned, performed throughout the entire M&S life cycle, and documented.
4	V&V may require some independence from the developer to prevent bias.
5	M&S validity does not guarantee the credibility and acceptability of simulation results.
6	Credibility can be claimed only for the prescribed conditions for which the model or simulation is VV&A'd.

Acquisition Risk Management, an SA-CMM Level 3 capability, is also applicable throughout the acquisition process, as shown by the *Risk Mitigation* middle circle. Risk management capabilities are particularly critical during the final stages of M&S acquisition, when the credibility and accreditation decisions are made. As the organization matures, the capability to quantify risks and to track their probability and occurrence improves. Accreditation decisions, which assess the value of the M&S to the decision-makers, are particularly amenable to the types of statistical analyses that characterize advanced risk mitigation techniques. The use of the SA-CMM and the requirements that the software supplier be evaluated at SW-CMM Level 3 are initial steps in risk management.

V&V are continuous activities integrated throughout the M&S life cycle. It is the acquisition process that ensures appropriate system documentation is delivered with product releases to support the inspections that make up V&V. V&V plans and V&V reports then make up a body of evidence to demonstrate to the user whether and how the M&S was found to be suitable for the intended use. The next user will expect to establish suitability based on a similar V&V plan and subsequent V&V inspections, but will benefit from the "body of evidence" already developed in the form of the V&V report from the first accreditation. Thus, the acquisition process ensures that documentation processes make the first accreditation possible without exorbitant costs. Then, each subsequent accreditation need only determine what V&V tasks are unique to the new use (haven't already been V&V'd and documented in the existing body of evidence). Credibility in the M&S can be maintained when all changes are controlled and documented and when the user can see that his requirements have been already V&V'd or are being addressed through additional inspection. The authority that accredits the M&S for use determines how much V&V is needed. The Accreditation Authority assumes the risk whenever funds will not cover the V&V tasks deemed most important. The Accreditation Authority will demand a level of V&V effort commensurate with the perceived risk. Logically, then, an M&S used for decisions which affect lives, large sums of taxpayer dollars, or force capabilities will require more V&V "evidence" than an M&S used for demonstration purposes only.

Figure 2 is complimentary to the management principles in Table 1 and depicts essential VV&A activities overlaid upon the M&S development process. Each process starts by stating the problem to be solved and specifying the requirements necessary to solve it (Principles #1 and #2).

Requirements Verification deals with justifying that all requirements have been supported and that the transformation into code has been implemented correctly. In order to verify that a requirement has been correctly captured in code, the requirement must be unambiguously

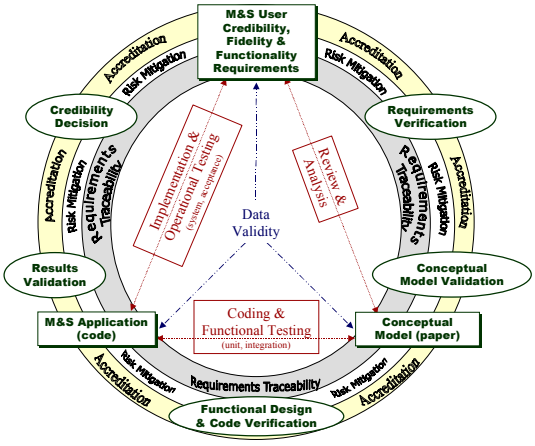

Figure 2: M&S VV&A Overlay

stated. The art of eliciting requirements from a user may be one of the most useful skills of a V&V agent simply because the job of V&V cannot even begin without at least a first cut on requirements. Requirements should be as complete as possible, but kept to the bare minimum required for the M&S application.

Management Principle #3 states that *"VV&A must be planned, performed throughout the entire M&S life cycle, and documented."* Balci (1998) points out that when under pressure to complete an M&S effort, VV&A and documentation are often sacrificed first. When this happens, it is an indication that the acquiring organization has immature acquisition processes. A mature acquisition organization would have clearly defined the problem to be solved, specified requirements that were necessary to solve the problem, allocated funding for design, development and VV&A, and then managed the acquisition to ensure all requirements were met. An M&S proponent, sponsor or manager must plan for, fund and require the developer to apply VV&A throughout the entire M&S life cycle. Documentation is the only proof that V&V were accomplished and is required for accreditation.

Conceptual Model Validation is performed to determine whether the assumptions, algorithms, modeling concepts, data types and sources, and (where necessary) architecture of the conceptual model provide an acceptable representation of the subject modeled for the intended application of the model or simulation. Architectural features of the software should be covered only when they constrain or drive the model algorithms. Distributed simulation is one clear example where algorithms must involve timing considerations.

Functional Design Verification determines if a model implementation accurately represents the developer's conceptual description and specifications to ensure that it reflects the validated concept and verified requirements. The functional design is the developer's blueprint for the development of the M&S.

Code Verification evaluates the extent to which the M&S application was coded using sound and established software engineering techniques. To put it another way, functional design and code verification determines if the model or simulation built in the software is the model or simulation described in the conceptual model. Failure to develop an adequate conceptual model prior to final design and implementation is a major cause of requirements-creep, cost over runs and schedule delays. Agreement on the conceptual model, before coding, will always save many hours of design, code and debugging.

Results Validation is the formal test and analysis process that compares the responses of the M&S with known or expected behavior from the real world object it represents. This is done to determine that the M&S responses are sufficiently accurate for intended use or uses. Principle #4 states that some independence from the developer may be required to prevent bias. The authority accrediting the M&S for use decides whether or not and how much independence is required.

V&V are conducted at the level determined by an overall *Risk Mitigation* strategy. Risk mitigation analysis is an integral part of V&V planning and determines the level of effort for V&V tasks. Risk analysis is performed to allocate V&V resources to the most critical components of a model or simulation. Requirements are prioritized and continually assessed throughout the development. These priorities flow down to the software and simulation system requirements and to the software and simulation system design and implementation.

Requirements Traceability through all stages of development helps ensure that the user's needs are being met in the implementation and provides the accrediting authority confidence throughout the development.

Accreditation is a continuous process ultimately resulting in the *Credibility* Decision. Accredited means that the model went through a formal review process and sufficiently meets all requirements. Accreditation is the determination by the end user that a model or simulation is right for the intended use or uses. The end user is the accrediting authority. The credibility decision determines whether (1) to accredit the M&S for the specific applications; (2) to require additional tests or information; or (3) to disapprove accreditation.

Principle #5 cautions the user to remember that M&S validity does not guarantee the credibility and acceptability of simulation results. While Principle #6 reminds the user that credibility is established based on the requirements for the prescribed conditions the model or simulation was verified, validated and accredited.

5 APPLYING THE CMMs

The CMMs provide the frameworks to achieve needed improvement for our software acquisition and software development processes. By institutionalizing better processes for M&S acquisition and development, organizations can incorporate requirements for VV&A at the beginning of the acquisition cycle, manage those requirements throughout the design and development, mitigate risks, and build confidence in a functionally superior, more credible M&S product.

Table 2: Maturity Levels 2 and 3

Level	SA-CMM	SW-CMM
2 Repeat-able	1. Basic software acquisition project management processes established to: • plan all aspects of the acquisition • manage software requirements • track project team and contractor team performance • manage the project's cost and schedule baselines • evaluate the products and services, and • successfully transition the software to its support organization 2. Project team reacting to circumstances. 3. Process discipline in place to repeat earlier successes	1. Basic project management processes are established to track cost, schedule, and functionality 2. The necessary process discipline is in place to repeat earlier successes on projects with similar applications.
3 Defined	1. Documented standard software acquisition process 2. All projects use tailored version for acquiring software products and services 3. Project and contract management activities are proactive 4. Risk management is integrated into all aspects of the project 5. Training provided	1. Organization-wide documented standard software process for management and engineering activities 2. All projects use a documented and approved version of the organization process for developing and maintaining software 3. Training provided

The SA-CMM and SW-CMM are synergistic. The two models should be used in parallel since they address the same requirements, proceed on the same schedule, and pursue the same objective - high quality deliverables. Each CMM identifies key process areas (KPAs) for four of five levels of maturity. The KPAs state goals that must be satisfied to achieve each level of maturity and the levels must be achieved sequentially.

In this paper we address the impacts of Levels 2 and 3 on M&S development. Maturity Level 1 (Initial) of both models is characterized as ad hoc and chaotic, with few processes defined and success depending on individual effort. Maturity Levels 2 (Repeatable) and 3 (Defined) are described in Table 2. Maturity Levels 4 (Quantitative) and 5 (Optimizing) further refine the process focus.

The CMMs describe KPAs with related activities and processes that are necessary to achieve the goals consid-

ered important to appraise an organization's capability. We introduce the selected KPAs below.

5.1 Acquirer's Role

The SA-CMM (Cooper et al. 1999) describes the acquirer's role in the software acquisition process and addresses the functions that support the acquisition of software. The SA-CMM provides a structured framework to guide and appraise organizations in maturing their acquisition capabilities both in the acquiring and maintenance phases of the M&S life cycle.

Although the SA-CMM currently is not mentioned in DoD policy, organizations cannot continue to afford having immature acquisition capabilities. An SW-CMM Level 3 development effort coupled with an SA-CMM Level 1 acquiring effort can often lead to a SW-CMM Level 1 delivery capability. While the Level 3 developer is often criticized for an inferior product, the reality is that an immature acquirer can force poor practices upon the developing organization (Jarzombek 1999).

5.1.1 SA-CMM Level 2 Repeatable

The process capability of a Level 2 acquisition organization is stable for planning and tracking the software acquisition because documented procedures provide the environment at the project level for repeating earlier successes. One Level 2 KPA is of prime importance to M&S acquisition:

Requirements Development and Management. Establishes a common and unambiguous definition of requirements that is understood by everyone involved from the project team, to the M&S proponent, sponsor, manager, developer, tester and user.

Requirements development and management begins with the translation of operational or user requirements into specifications and ends with the transfer of responsibility for the support of the software products. Direct participation from the M&S user is needed to ensure that system-level requirements are well understood. The process ensures that software requirements are baselined and that all subsequent requirements changes are controlled. Requirements management includes establishing and maintaining agreement among people involved in the acquisition with the objective of specifying requirements that are unambiguous, traceable, verifiable, documented, and controlled.

To summarize, the goals of Requirements Development and Management are:

1. Requirements are developed, managed, and maintained.
2. The end user and other affected groups have input to the requirements over the life of the acquisition.
3. Requirements are traceable and verifiable.
4. The requirements baseline is established prior to release of the solicitation package.

5.1.2 SA-CMM Level 3 Defined

The process capability of Level 3 acquisition organizations can be summarized as being controlled, since performance, cost, schedule, and requirements are under control and software quality is tracked.

At this level, the acquisition organization's standard software acquisition process is established, including the processes for software contract management and internal project management. Management and engineering activities are integrated. Risks are identified and managed throughout the acquisition.

The Risk Management KPA has the most direct impact on containing the costs of M&S V&V.

Acquisition Risk Management. Identifies risks as early as possible, adjusts the acquisition strategy to manage those risks, and develops and implements a risk management process.

Risk management is the process associated with identifying risks, evaluating their impact and probability, developing strategies to mitigate the effect, tracking each risk, and implementing the defined mitigation strategy when required. A Level 3 acquisition organization has a defined process for identifying and quantifying risks associated with software acquisition. The risks can be tracked in a controlled manner, so that mitigating action can be taken at the appropriate time.

5.1.3 Application to M&S Acquisition

Figure 3 depicts the application of the SA-CMM to M&S. As shown on the upper right, SA-CMM Level 2 maturity for *Requirements Development and Management* is essential during creation of the Conceptual Model. Once established, this capability facilitates the on-going Requirements Traceability process shown in the innermost circle. The unambiguous definition of requirements embodied in the Conceptual Model is the controlling factor for design and coding of the software model or simulation. If requirements must change during or post software development, the traceability to the baseline and rationale for the change needs to be captured to ensure consistency across the product and to support the credibility and accreditation decisions.

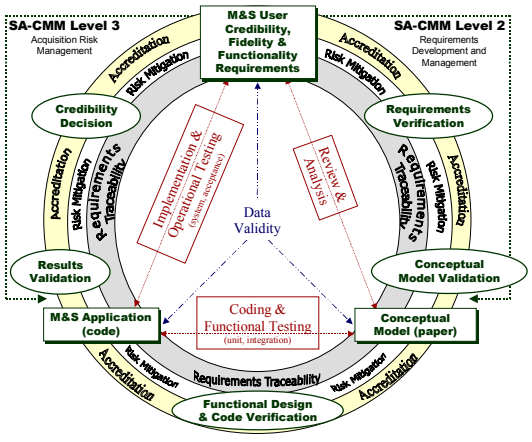

Figure 3: Application of the SA-CMM

Acquisition Risk Management, an SA-CMM Level 3 capability, is also applicable throughout the acquisition process, as shown by the *Risk Mitigation* middle circle. Risk management capabilities are particularly critical during the final stages of M&S acquisition, when the credibility and accreditation decisions are made. As the organization matures, the capability to quantify risks and to track their probability and occurrence improves. Accreditation decisions, which assess the value of the M&S to the decision-makers, are particularly amenable to the types of statistical analyses that characterize advanced risk mitigation techniques. The use of the SA-CMM and the requirements that the software supplier be evaluated at SW-CMM Level 3 are initial steps in risk management.

Disciplined requirements management is essential to a successful M&S effort. Any organization acquiring M&S should be operating at Level 3 to ensure the ultimate delivery of a well-built, quality software product that meets all specifications, and is produced on schedule and within budget.

5.2 Developer's Role in Modeling and Simulation

The SW-CMM (Paulk et al. 1993) describes the software developer's role and addresses software engineering functions. The SW-CMM provides a framework for appraising the maturity of an organization's software development capabilities. The software developer can use the SW-CMM to determine current process maturity and as guidance in selecting process improvement strategies. An acquisition organization can use the SW-CMM as an auditing tool to judge the maturity of its software providers.

5.2.1 SW-CMM Level 2 Repeatable

At the Repeatable Level, policies for managing a software project and procedures to implement those policies are established. The software process capability of Level 2 organizations is characterized as disciplined because planning and tracking are stable and earlier successes are repeatable.

The KPAs at Level 2 focus on establishing basic project management controls. Two KPAs with direct impact on M&S projects are *Requirements Management* and *Software Configuration Management.*

Requirements Management. Establishes a common understanding between the customer and the M&S project team of the customer's requirements that will be addressed by the M&S project.

The SW-CMM *Requirements Management* KPA is a direct parallel of the SA-CMM *Requirements Development and Management* KPA. The acquirer establishes the basic requirements, including non-technical requirements such as milestones and schedule. These requirements are the basis for the contract between the acquirer and the provider. The software provider uses them as the basis for establishing cost and schedule, planning, performing, and tracking the M&S project activities. In order to maintain control of their activities, developers must review initial requirements, baseline their allocation to software, and review / adjust all planning documents if requirements change. Requirements bound the M&S project; remaining cognizant at a management level of all changes to requirements helps contain requirements-creep and the escalating costs and schedule delays it causes.

Software Configuration Management. Establishes and maintains the integrity of the M&S product throughout the product's software life cycle.

Configuration management involves identifying the exact version of all software that would be needed to replicate the M&S product at specified points in time, controlling changes to that software, and maintaining traceability of those changes. The software under configuration management must include any software delivered to the customer and commercial software, such as compilers, that might change the performance of the delivered software. Many tools are available to support change control and traceability. Proof of configuration management is a requirement for accreditation.

5.2.2 SW-CMM Level 3 Defined

In a Level 3 organization, standard organization-wide software processes are in place, along with a training program to develop identified management and technical skills. Each project may tailor the organization's standard software processes to create a coherent, defined software process that meets the needs of the particular project. The commonality of the standard software process promotes better upper management insight into a project and allows projects to share data and "lessons learned" more easily.

The KPAs at Level 3 address both project and organizational issues, as the organization establishes an

infrastructure that institutionalizes effective software engineering and management processes. Two Level 3 KPAs especially pertinent to M&S are *Software Product Engineering* and *Peer Reviews.*

Software Product Engineering. Consistently performs a well-defined engineering process that integrates all the software engineering activities to produce correct, consistent M&S products effectively and efficiently.

Product engineering is the application of the project's software process to the technical activities of the project. The Requirements Management processes, developed primarily as a tracking mechanism in Level 2, are expanded to include active analysis and rationale development. Software architecture and code design become controlled, rather than ad hoc, efforts. Testing is to requirements, rather than to software design. A consistent, well-defined development process reduces risk and builds the customer's confidence in the M&S product.

Peer Reviews. Remove defects from the M&S products early and efficiently.

Peer reviews involve a methodical examination of software and related documentation by other programmers to identify defects and possibilities for improvement. Peer reviews have proven highly effective in detecting errors prior to test; with some programs showing as much as an 80 percent reduction in coding errors. Delivering M&S products that function correctly will gain the user's confidence.

5.2.3 Application to M&S Development

The SA-CMM and SW-CMM are synergistic and should be used in parallel since they address the same requirements, proceed on the same schedule, and pursue the same objectives.

Figure 4 shows the effectiveness of the SW-CMM in the M&S development and VV&A processes. SW-CMM is applicable primarily during the coding and functional testing phase, although its effect will be felt throughout in the ongoing Requirements Traceability and Risk Mitigation tasks.

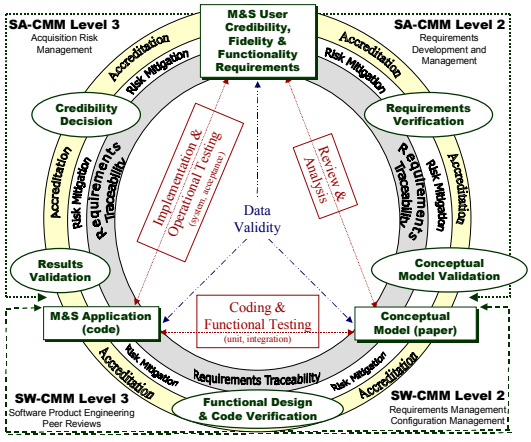

Figure 4: Applying the SW-CMM

The Level 2 emphasis on project management and tracking is felt during the early stages of software requirements analysis. A solid contract, based on mutual understanding of what needs to be done, is built on the Requirements Management processes. Early establishment of configuration management ensures the integrity of the software being built.

At Level 3, the SW-CMM incorporates a larger technical focus. The product engineering and peer review concepts institutionalize traceability of all technical requirements from M&S product development inception through testing.

6 SUMMARY

Acquisition of M&S requires effective VV&A to ensure that the acquired product will represent the desired real-world systems, at the level of fidelity and detail needed by the M&S uses. Effort and activities directly attributable to VV&A need to be planned for and costed as part of total acquisition expense. The cost of these activities can be contained and reduced by applying the SA- and SW-CMMs.

In order for the M&S to be useful, it must be developed by a disciplined process that provides the requirements traceability and documentation needed to conduct V&V. Accreditation and credibility are results of successful inspection of the documentation generated during development With disciplined processes, confidence is designed and developed into the M&S product from the beginning of the acquisition life cycle.

By using the CMM maturity level, an understanding of expectations is established between the acquirer and provider. This reduces the risk on both sides.

Costs associated with the V&V of the model or simulation are reduced by the accumulation of process-related evidence required by CMM compliance. Many of the products, especially those related to requirements management and tracking, support the accreditation and creditability decisions.

By implementing sound software engineering practices through acquisition, we ensure a baseline of requirements traceability and documentation that is critical to the successful V&V.

Accreditation, as a process designed to reduce the customer's risk in the use of M&S, will be feasible and affordable if the required V&V tasks are supported by processes and documentation set in place through the acquisition process. The V&V tasks do not duplicate the testing or documentation implemented through the acquisition process; instead, V&V is designed to review existing documentation and testing on behalf of the customer. In some cases, additional testing or inspection may be required to ensure that the system meets the customer's unique requirements, but the cost and effort

involved with VV&A will be significantly reduced once good software engineering discipline is enforced through acquisition practices.

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