



# Expanding the Focus of Software Process Improvement to Include Systems Engineering

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*There is a growing interest in improving the efficiency of systems engineering in organizations that develop software-intensive systems. A number of organizations have demonstrated that it is possible to increase software process capability through software process improvement programs. As a result, there is a heightened interest in improving the processes used in systems engineering of software-intensive systems using systems engineering process improvement programs. This article addresses some motivations for improving the systems engineering process, gives an overview of systems engineering process models, and identifies how to leverage an organization's successes in software process improvement.*

There is a long history of organizations performing impressive feats of systems engineering (SE). The growing complexity of software-intensive systems has made SE increasingly important for embedded systems and information systems.

Although there is no generally accepted single definition of SE, the pursuit of excellence in SE continues (see sidebar – Systems Engineering Definitions). Increased interest in systems engineering is evident from the following:

- The creation and growth of the International Council on Systems Engineering (INCOSE).<sup>1</sup>
- The development of systems engineering process models.
- The government supported integration efforts for use of systems engineering models.

This article is written for the benefit of an organization or enterprise that contains multiple groups, some with responsibility for SE activities and others with responsibility for software engineering activities.

For the most part, the business of these organizations is oriented to the development of one or more software-intensive products such as printers, cellular telephones, automobiles, and weapons. The organization typically has a product development focus with product-focused groups that work with one or more other groups such as component engineering, software de-

velopment, marketing, sales, manufacturing, and service. The organization executes a product development lifecycle from which the various versions of the product are developed and released. It is recognized that many of these concepts also are applicable to information systems development.

Information systems development has a similar set of considerations, though the domains being brought together as a system might be different. The new information system may require development or acquisition of a computing platform, development or acquisition of software, definition of new processes, creation of training, hiring of a new team of workers, and establishing a help desk. Integrating all

of these disciplines around the creation of the new system requires many of the same processes as the systems engineering of product-focused groups. For simplicity and clarity, this article deals with product-focused organizations.

## Systems Engineering Process Models

Since 1992, several groups have developed SE process models. These groups include representatives from industry and government organizations with an established record of accomplishment in systems engineering of large complex systems. Table 1 gives a summary of three of the models that resulted from this work.

## Systems Engineering Definitions

### Systems Engineering – Definition 1

"Systems Engineering is the selective application of scientific and engineering efforts to

Transform operational need into a description of the system configuration that best satisfies operational need according to measures of effectiveness. Integrate related technical parameters and ensure compatibility of all physical, functional, and technical program interfaces in a manner that optimizes total system definition and design.

Integrate efforts of all engineering disciplines and specialties into total engineering effort."<sup>5</sup> – *Systems Engineering Capability Maturity Model, Version 1.1.*

### Systems Engineering – Definition 2

"Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems."<sup>6</sup> – *Draft version 0.5 of the Systems Engineering Capability Model EIA 731-1.*

Close examination of the Systems Engineering Capability Maturity Model<sup>SM</sup> (SE-CMM<sup>®</sup>)<sup>2</sup> [1], Systems Engineering Capability Assessment Model (SECAM) [2], and Systems Engineering Capability Model (SECM) [3] shows they have

- The same (continuous) architecture.
- Many of the same authors.
- Similar process or focus areas divided into categories for technical, management, and organizational elements [4].

To illustrate some of the attributes of an SE process model, Table 2 lists the 18 process areas of the SE-CMM. The table is divided into three categories: Engineering, Project, and Organizational. Process areas (or focus areas) of the SECAM and SECM are nearly identical; however, for consistency, the SE-CMM process names will be used throughout the remainder of this article.

The architecture of the SE-CMM is continuous, as is the architecture of the SECAM and the proposed architecture of the SECM models. The CMM for software uses a staged architecture.

### Staged Architecture Models

Staged models provide guidance to organizations on the order of improvement activities they should undertake based on (key) process areas at each stage or maturity level. Performing the practices in the appropriate process area at a given level will help stabilize projects and allow the execution of further improvement activities. Because all stages contain a collection of process areas on which to focus current activities, incremental improvement is supported in each maturity level or stage.

Each stage provides the foundation for the next stage, which promotes the “crawl before you walk” approach. However, some organizations will decide, for business or cultural reasons, to address certain process areas earlier than defined by the stages. For example, users of the CMM for software often address some Level 3 key process areas (KPAs) while the organi-

Systems Engineering Capability Maturity Model (SE-CMM)		
Developer: Enterprise Process Improvement Collaboration. Members from Lockheed Martin, SECAT LLC, Hughes, Department of Defense, Federal Aviation Administration, Software Productivity Consortium, Software Engineering Institute (SEI), Texas Instruments, National Institute of Standards and Technology, and others. (Released as SEI documents.)		
Architecture: Continuous	Elements: 18 Process Areas	Categories: Engineering, Project, and Organization
Current Version: SE-CMM, Version 1.1 published November 1995	Availability: No charge on the Web. See Frameworks Quagmire <a href="http://www.software.org/quagmire">http://www.software.org/quagmire</a>	Assessment Method: SE-CMM Appraisal Method, Version 1.1. March 1996
Status: The model is used by organizations around the world with third-party appraisals performed by organizations including TeraQuest, SECAT, and the Software Productivity Consortium.		
Systems Engineering Capability Assessment Model (SECAM)		
Developer: Capability Assessment Working Group of the International Council on Systems Engineering (INCOSE) with initial members from Grumman, Hughes, CSC, Loral, and Software Productivity Consortium (149 contributors through Version 1.50).		
Architecture: Continuous	Elements: 19 Key Focus Areas	Categories: Systems Engineering, Management, and Organization
Current Version: SECAM, Version 1.5 published July 1996.	Availability: Information available at <a href="http://www.incose.org">www.incose.org</a>	Assessment Method: Systems Engineering Capability Assessment Method
Status: Assessments being performed by INCOSE members.		
Systems Engineering Capability Model (SECM)		
Developer: Electronics Industries Association (EIA) G-47 Systems Engineering Committee. Project members include EPIC, INCOSE, and EIA representatives. This is a merger of the SE-CMM and the SECAM intended to replace the two with a single model that will serve as an International Organization for Standardization standard.		
Architecture: Continuous	Elements: 19 Focus Areas	Categories: Technical, Management, and Environment
Current Version: EIA IS 731 was presented for ballot distribution April 20, 1998. Could be published as an interim standard as early as July 1998.	Availability: As of this writing, not publicly available.	Assessment Method: To be included in the interim standard.
Status: Under development. Interim standard designation was selected because work on CMMI is expected to require SECM modification within a year.		

Table 1. SE process models.

zation is working on Level 2. Typically, an organization establishes a Software Engineering Process Group and begins work on the Organization Process Definition and Organization Process Focus (Level 3) KPAs. Another example is an organization that implements defect analysis (from the Level 5 KPA Defect Prevention) before establishing Level 2 processes. There are many cases where these early implementation approaches have led to failure or slow progress. This is often the case because foundation processes

such as project planning and tracking are missing, or because organizations lack focus from trying to incorporate too much change at one time.

**Continuous Architecture Models**  
Continuous models provide more flexibility in defining process improvement programs. These models recognize that individual process areas are performed at distinct capability or maturity levels. Based on the institutionalization of the base practices of that process area, a continuous model

Engineering Process Areas	Project Process Areas	Organizational Process Areas
1. Analyze Candidate Solutions	8. Ensure Quality	13. Define Organization's Systems Engineering Process
2. Derive and Allocate Requirements	9. Manage Configurations	14. Improve Organization's Systems Engineering Process
3. Evolve System Architecture	10. Manage Risks	15. Manage Product Line Evolution
4. Integrate Disciplines	11. Monitor and Control Technical Effort	16. Manage Systems Engineering Support Environment
5. Integrate System	12. Plan Technical Effort	17. Provide Ongoing Knowledge and Skills
6. Understand Customer Needs and Expectations		18. Coordinate with Suppliers
7. Verify and Validate System		

Table 2. *Process areas of the CMM.*

assessment provides a profile with specific maturity levels for each process area.

In the SE-CMM, the SE activities performed for a process area are structured as base practices within each process area. For each level of the process area, exemplary generic practices apply. For example, the generic practices for each level are:

- Level 1 – perform the process.
- Level 2 – document the process.
- Level 3 – tailor the standard practice.
- Level 4 – determine process capability.
- Level 5 – continuously improve the standard process.

To use these models for process improvement, organizations must perform an analysis of how the various processes address their needs. This takes advantage of the inherent flexibility of the model. Such an exercise also provides an opportunity for the organization to gain consensus on the sequence of appropriate organization-wide improvement activities.

Considering their understanding of staged models, a number of organizations with a significant investment in software CMM-based software process improvement (SPI) have sought an SE process model with a staged architecture. Having a staged SE model makes it easy to describe the model content to people in the organization and eases the integration of SE improvement

activities with current software process improvements.

Table 3 shows an SE staged model developed by mapping the SE-CMM process areas and generic practices onto four levels. This model was developed by the Process-Oriented Systems Engineering (POSE) project. The POSE project is a process improvement experiment that is part of the

European Systems and Software Initiative. The POSE project is managed by Thomson-CSF with additional members from TeraQuest Metrics, Inc. and the European Software Institute.

Corporations with multiple organizations or multiple business units can use such a model to support a synergistic approach to SE process improvement across the corporation. A review of process areas and generic practices associated with each level reveals that staging is roughly equivalent to the CMM for software.

This example SE model is incremental, with each stage building on the next. That is, to perform at Stage Two, an organization must perform the Level 2 generic practices listed in the left column for all eight of the process areas listed in the right column. To perform at Stage Three, an organization must perform the Level 2 and Level 3 generic practices for the Stage Two and Three process areas. Stage Four organizations perform Levels 2, 3, and 4 generic practices for

Table 3. *POSE Systems Engineering Staged Model (Version 2.0, May 1998).*

	Generic Practices	Process Areas
Stage Two	<i>Level 2 – Planned and Tracked</i> <ul style="list-style-type: none"> <li>• Planning performance</li> <li>• Disciplined performance</li> <li>• Verifying performance</li> <li>• Tracking performance</li> </ul>	Understand Customer Needs and Expectations (PA 6) Derive and Allocate Requirements (PA 2) Coordinate with Suppliers (PA 18) Plan Technical Effort (PA 12) Monitor and Control Technical Effort (PA 11) Manage Configurations (PA 9) Establish Quality Assurance (PA 8 – split) Control Contract (additional PA)
Stage Three	<i>Level 3 – Well Defined</i> <ul style="list-style-type: none"> <li>• Defining a standard process</li> <li>• Performing the standard process</li> </ul>	Define Organization's SE Process (PA 13) Provide Ongoing Knowledge and Skills (PA 17) Evolve System Architecture (PA 3) Integrate System (PA 5) Verify and Validate System (PA 7) Integrate Disciplines (PA 4) Adopt Product Line (PA 15 – split) Manage Risks (PA 10)
Stage Four	<i>Level 4 – Quantitatively Controlled</i> <ul style="list-style-type: none"> <li>• Establishing measurable quality goals</li> <li>• Objectively managing performance</li> </ul>	Ensure Quality (PA 8 – split) Manage SE Support Environment (PA 16)
Stage Five	<i>Level 5 – Continuously Improving</i> <ul style="list-style-type: none"> <li>• Improving organizational capability</li> <li>• Improving process effectiveness</li> </ul>	Improve Organization's SE Process (PA 14) Manage Product Line Evolution (PA 15 – split)

all process areas through Stage Four. Finally, Stage Five organizations must perform all generic practices for all process areas.

In two process areas, it has been necessary to split the process area across stages. An example of a split process area is Ensure Quality, which has been split into two process areas: Establish Quality Assurance at Stage Two and Ensure Quality at Stage 4. The POSE project also chose to remove the Analyze Candidate Solutions (PA 1) process area and add the Control Contract process area.

### Process Mismatch – Why Should You Care?

Organizations cannot perform to their full potential with a mismatch in the capability of the processes used by different development groups within the organization. A process mismatch exists when the software and systems processes operate at different levels of

maturity. Consequently, organizations experience the following:

- Difficulty in communication and commitments between project groups.
- Inability to effect improvements to their overall processes.
- Overall performance below the capability of the individual software or systems processes when considered on their own merit.

This situation becomes more evident as the number of organizations making significant progress in SPI increases. In these organizations, software processes are often at a higher maturity level than the SE processes. This is not an indication of the ability or professionalism of the engineers, but an indication of unaligned processes. There also are cases of higher maturity level systems groups that have interface mismatch problems with lower-level software groups; however, not much data exists since the number

of systems assessments remains relatively low.

Given the cost associated with product development and process improvement activities, it is prudent to promptly address these mismatches in capability. For example, an organization performing at CMM Level 1 needs to focus on the mechanisms by which project commitments are made and kept. They need to make cooperative commitments with the SE organization. For the development of the product, in such a case, both the software organization and the SE organization need project plans with adequate visibility into the market commitments and into their respective work. No other technical advances in the SE organization can make up for a mismatch in the basic commitment process.

The following sections are divided by software CMM maturity levels, and they discuss what the software development group needs from the SE group for the organization to best exploit the SPI investment. This involves leveraging the strengths of the systems engineering group in a collaborative manner so that the organization meets its overall goals.

### Level 2

A CMM Level 2 organization supports the basic commitment process. Requirements and schedules from and with SE are key to this success. Typically, software commitments are made between software project managers and agents of the product development groups such as program managers and systems engineers. The software organization needs the following from these agents

- Well-defined requirements (particularly those allocated to software).
- Negotiable schedules.
- A stable physical architecture.

### Level 3

A CMM Level 3 organization supports the required infrastructure for using a defined process. The essential element is coordination of all activities between the multiple disciplines and groups collaborating to build a prod-

Table 4. Contributions of systems engineering to process capability.

Level	Organizational Behavior	System Engineering Contribution	SE-CMM Process Areas
2	Commitments	• Well-Defined Requirements	• Derive and Allocate Requirements (Pa 2) • Understand Customer Needs and Expectations (PA 6)
		• Negotiable Schedules	• Manage Risks (PA 10) • Monitor and Control Technical Effort (PA 11) • Plan Technical Effort (PA 12)
		• Stable Physical Architecture	• Derive and Allocate Requirements (PA 2) • Manage Configurations (PA 9)
3	Organization-Wide Standardization	• Well-Understood System Architecture	• Evolve System Architecture (PA 3) • Integrate System (PA 5) • Verify and Validate System (PA 7) • Manage Configurations (PA 9)
		• Well-Defined Organizational Processes	• Define Organization's Systems Engineering Process (PA 13) • Improve Organization's Systems Engineering Process (PA 14)
		• Clear Organizational Interfaces	• Integrate Disciplines (PA 4)
4	Quantitative Understanding	• Well-Managed Product Line Evolution	• Manage Product Line Evolution (PA 15)
		• Well-Managed Engineering Support Environment	• Manage Systems Engineering Support Environment (PA 16)
5	Continuous Improvement	• Organization-Wide Quality Focus	• Ensure Quality (PA 8)
		• Continuous Improvement of Defined Processes	• Improve Organization's Systems Engineering Process (PA 14)



Organizational Consideration				
Approaches	Existing Software Process Improvement Program	Focus of Engineering Organization	Urgency of Change	
1	Use Existing SE Model	(+) May help get buy-in from Systems Groups (-) May not exploit the existing program's work	(+) If systems focused (-) If software focused	(+) Project Process Areas provide triage (+) Available today
2	Add System Process Areas to CMM for Software	(+) If at software Level 3, can add Engineering Process Areas just like Software Product Engineering KPA	(+) If software focused (-) If system focused	(-) Will take some time and effort to define merger
3	Add Software KPAs to SE Model	(-) May not make best use of existing Software Process Improvement Infrastructure	(+) If systems focused (-) If software focused	(-) Will take some time and effort to define merger
4	Wait for SECM or CMMI to complete	(+) No impact on current program (-) No impact on current program	(+) CMMI should provide for a merged focus	(-) Likely to be some time in coming

Table 5. Approach consideration matrix.

uct. The product development groups need to ensure that they all have the following with which to work.

- A well-understood system architecture.
- Well-defined processes.
- Clear organizational interfaces.

Systems architecture is defined as “The fundamental and unifying system structure defined in terms of system elements, interfaces, processes, constraints, and behaviors.”<sup>3</sup>

#### Level 4

A CMM Level 4 organization provides a clear and quantitative definition of its products and processes. Organizations moving into Level 4 begin to see increased benefit from reuse programs as the products produced by the organization have a higher recognized quality. The product development groups need to provide the following:

- A well-managed product line evolution.
- A well-managed engineering support environment.

Product-line engineering is defined as “The engineering of a family of products that is developed using a domain analysis approach and share the same system architecture.”<sup>4</sup>

#### Level 5

A CMM Level 5 organization performs continuous process and product improvement. Through defect analysis, the organization identifies root causes and eliminates them at the source. The product development groups need to provide the following:

- An organization-wide quality focus.
- Continuous improvement of defined processes.

Table 4 summarizes the above and provides a cross-reference to the specific SE-CMM process areas that

support each software CMM level as described above.

### Using the SE Capability Models

After reviewing the systems engineering process models and reading about the CMM integration activities (see sidebar – CMM Integration Project), many organizations have asked the following questions.

- How can we use these various models?
- What should we do next?

The answer to the first question is familiar to those who have been performing SPI: Any one of the SE models can be used to identify process assets, perform systems engineering process assessments, and identify and exploit the organization's best practices. The key—prompted by the number of models as well as the changes in these SE models—lies in the second question. The answer to the second question is to select one of the following alternative approaches (Table 5).

Approach 1 – Use an existing systems model (SE-CMM or SECAM).

Approach 2 – Add System Process Areas to the software CMM.

Approach 3 – Add software KPAs to a systems model.

Approach 4 – Wait until one of the integration efforts is completed.

## CMM Integration Project

The CMM integration project [5] was initiated in response to organizations using multiple process models that need a consistent process model to apply to improvement activities. The project is sponsored by the U.S. DoD, Office of the Secretary of Defense for Acquisition and Technology at the Software Engineering Institute. A product of the integration project is the Common CMM Framework (CCF), which allows for both continuous and staged model representations (CCF Draft E). The CCF is represented by a set of standard requirements for all CMMs. Little public information is currently available; however, the CMMI Web page at [www.sei.cmu.edu](http://www.sei.cmu.edu) promises additional information on an ongoing basis. The stated project goals are to

- Enable accelerated release of a software CMM equivalent to Version 2.0, Draft C under CCF, which is ISO 15504 compatible.
- Provide complete product suite—complete model plus assessment and training materials.
- Provide opportunities for all industry and government organizations to participate.

To select between the alternatives, the organization needs to consider the current improvement programs, the engineering focus of the organization and its products, and the level of need or urgency for change.

### Current Improvement Programs

The aim is to exploit any successes, momentum, and products of existing SPI programs. The organization should consider the following questions.

- Is there an active SPI program?
- Is it well accepted by the organization?
- Is the program making progress?
- Is the organization now working to attain Level 3 or above?

If the answer to some or all of these questions is “yes,” there are strong reasons to leverage this momentum. On the other hand, if the ongoing SPI program is slow moving, not accepted, or regressing, it may be wiser to start over with a fresh approach.

### Organization’s Engineering Focus

The organization’s engineering focus or cultural perspective will have an impact on how best to approach the problem. The organization should consider the following questions.

- Is the organization primarily in the business of producing systems or software?
- What is the focus of most new development?
- Where is the locus of control?

If the business is a software business inside another apparent business, it is wise to focus on the software CMM.

### Urgency for Change

A pressing need that is visible to the organization motivates action. The organization should consider the following questions.

- Is the organization facing near death?
- Is there a major program in trouble?

Organizations that are in significant trouble or almost going out of business are sometimes more willing

to proceed with improvement efforts than successful organizations. Such organizations can use the information from the process areas to address immediate project issues.

Table 5 shows the positive and negative impact of these organizational considerations based upon the four approaches. For example, the first approach (Use Existing SE Model) is an effective choice for organizations that are seeking buy-in from their systems groups, need quick improvement of their overall project management capabilities, and need something immediately. The buy-in is easier with these models since they were developed by systems engineers for systems engineering. As such, these models can be used as they exist today; what is needed is an integration of the chosen SE model with the organization’s current SPI efforts, either through an organizational integration effort or through an external integration project.

### Recommendations

In spite of the various SE models and the development activities surrounding them, we strongly suggest that you do not wait. Based on your situation, select any of the first three approaches suggested above and get started. Although work is proceeding on the integration of the systems process models, these integration activities will take some time before a model emerges that meets the ever-growing set of needs. Further, an SE process improvement (SEPI) program based on one of the existing models should require minimal effort to migrate to a new model when it becomes available. Remember that all the models are developed from the same basic source materials. The benefit of progress from an active SEPI program should outweigh any risk of rework that results from a new SE model. The risk can be minimized by staying current with model developments and making progress in your SEPI program. ♦

### About the Authors



**Kent A. Johnson** is the director of systems engineering for TeraQuest Metrics, Inc., where he has helped companies in five countries to improve their systems and software processes through systems and software assessments, training, and process-specific consulting. He is a former project manager of the Process and Methods Program at the Software Productivity Consortium (SPC). While at the SPC, he co-wrote the software and system development method, as well as led the team that helped create it, which is used by over 800 engineers in the development of the F-22 Advanced Tactical Fighter. He is also a co-author of the Spring-Verlag book, *Ada 95 Quality and Style*.

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### References

1. Bate, Roger, et al., *A Systems Engineering Capability Maturity Model*, Version 1.1, Handbook SECM-95-01, Software



This article can be found in its entirety on the Software Technology Support Center Web site at <http://www.stsc.hill.af.mil/CrossTalk/crostalk.html>. Go to the "Web Addition" section of the table of contents.

## DO-178B: Software Considerations in Airborne Systems and Equipment Certification

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*This is a practitioner's discussion of the evolution of the current practice and application of RTCA/DO-178B[1] for software approval in the commercial world. The objectives include developing and providing the data for development of educational material, providing the rationale behind the guidance for people new to the commercial certification environment, and clarification of the intent and application of DO-178B. The derivation of the software approval guidelines from the Federal Aviation Regulations to DO-178B is discussed to clarify its relationship to the government regulations. An explanation of the Designated Engineering Representative system is also provided along with a discussion of the safety process to describe the environment in which DO-178B is used. The evolution of the avionics industry that eventually led to DO-178B is included as part of the background behind the rationale of DO-178B. The key aspects of each version, from the original version to DO-178B, provide insight to the rationale for the inclusion and further development of the content. In addition, there are special considerations in using DO-178B concerning its current guidance for systems and highlights of the problem areas for those from a military culture. As the industry moves to use of commercial-off-the-shelf components, the incentive is greater to reconcile the difference between military standards and commercial standards. Trustworthiness of software is an absolute concept independent of the verification process used. This article explores the differences and similarities between DO-178B and MIL-STD-498 affecting the software development process.*

- Engineering Institute, Carnegie Mellon University, Pittsburgh, Pa., 1995.
2. SECAM: *Systems Engineering Capability Assessment Model*, Version 1.5, INCOSE, 1996.
  3. SECM: Not yet released; planned as EIA IS 731, Electronics Industries Alliance, Alexandria, Va.
  4. Sheard, Sarah A. and Jerome G. Lake, "Systems Engineering Standards and Models Compared," Software Productivity Consortium, Herndon, Va. (<http://www.software.org/pub/papers>), April 15, 1998.
  5. Schaeffer, Mark D., "Capability Maturity Model Process Improvement," *CROSSTALK*, Software Technology Support Center, Hill Air Force Base, Utah, May 1998.
  3. Definition approved by the Systems Architecture Working Group of INCOSE at INCOSE '96, Boston, Mass.
  4. Definition approved by the Systems Architecture Working Group of INCOSE at INCOSE '96, Boston, Mass.
  5. Army Field Manual, pp. 770-778.
  6. Definition approved by the International Council on Systems Engineering at the January 1996 workshop.

### Notes

1. INCOSE can be found at <http://www.incose.org>.
2. Capability Maturity Model is a service mark of Carnegie Mellon University. CMM is registered with the U.S. Patent and Trademark Office.



### New Crosstalk Phone Numbers

Some of Crosstalk's phone numbers have changed. Please use the phone numbers in the masthead on page 31.