8

SYSTEM ENGINEERING PROGRAM EVALUATION

Inherent within and part of the overall system engineering management activity is a four-step process: (1) the initial definition of system requirements, (2) the ongoing activity of fulfilling these requirements through a good and effective system design and development effort, (3) the measurement, evaluation, and assessment of the results, and (4) providing feedback and taking any necessary corrective action to achieve or exceed the initially specified objectives.

The subject of "requirements" has been emphasized to a great extent in Chapters 2 and 3. More specifically, the development of system operational requirements, the maintenance concept, and the identification and prioritization of technical performance measures (TPMs), described in Sections 2.4 through 2.6, constitute the steps involved in defining the requirements for the system. These requirements (which are also described in the various design-related sections in Chapter 3) are then allocated and apportioned downward to the various subsystems and below, and are included in the appropriate specifications (refer to Section 3.1). Through this allocation process, and resulting from decisions pertaining to outsourcing, the requirements for each of the different suppliers are then determined. In essence, this is where the process starts; that is, in the *definition of requirements.*

The next step is to identify the tasks that must be accomplished and the organizational approach that must be implemented to meet the overall objectives that have been identified through the requirements definition process. The tasks that must be completed, and the available technology applications to facilitate this effort, are discussed throughout Chapters 3, 4, 5, and 6. Initially, there is a planning process, which is covered rather extensively in Chapter 6. Program task schedules and cost projections are initiated, supplier requirements are identified, contractual requirements are negotiated, and program review and reporting requirements are established. In Chapter 7 the emphasis is on "organization" and the approach proposed for implementation of a program designed to fulfill the desired objectives as stated. Having identified the "WHATs" (i.e., What must be accomplished?), the next question relates to the "HOWs" (i.e., How can this be best accomplished?). Basically, the planning and organizational activities are discussed in depth in Chapters 6 and 7, primarily addressing the first two items in the four-step process mentioned earlier.

The next issue is "measurement, evaluation, feedback, and taking corrective action as required" (i.e., the third and fourth steps in the process). *Measurement* means determining, through both informal and formal reporting, the degree to which progress toward the meeting the objectives (requirements) is being made. The evaluation and reporting of Technical Performance Measurement (TPM) status in Figure 5.6 and the cost-schedule reporting in Figure 6.28 are examples of formal reports. In addition, reports covering the results from the formal design reviews are another source for determining status. *Evaluation* is determining cause and possible steps to take when there are significant deviations from the planned performance. *Feedback and corrective action* include the development and implementation of a plan to correct any deficiencies that may exist. Such a plan must be coordinated with the development of the Risk Management Plan described in Section 6.7.

This chapter discusses "measurement and evaluation" as they pertain to the implementation of a system engineering program. The primary area of emphasis is the organization and management of a system engineering department/group in fulfilling the objectives as stated throughout the earlier chapters in this text.

8.1 EVALUATION REQUIREMENTS

Although the introduction to this chapter points to the requirements associated with the design and development of a single system, or the requirements determined for a specific project, it should be noted that an established system engineering organization may be involved in many different projects concurrently; for example, the design and development of a large-scale system, the design of many different subsystems, the manufacture and testing of a large system element, and/or the monitoring of many varieties of supplier activities such as illustrated in Figure 6.38. As the requirements and system engineering tasks are varied, the system engineering organization must be able to respond to all of the functions described in Chapter 6 (Figure 6.6), across the board and at the same time.

Thus, the emphasis should be on "organizational development" and building capability so that the system engineering organization can be responsive to a wide mix of situations. As a start, the system engineering manager (with the support of key senior personnel both within and external to his or her organization) needs to define organizational objectives, goals, and responsibilities. To this end, it would be appropriate to establish a *benchmarking* capability and a model for the measurement and evaluation of the organization and its operations. The basic questions are, Where are we today? How do we compare with the competition (relative to both product and organization)? Where would we like to be in the future?

8.2 BENCHMARKING

The term *benchmark* may be defined in different ways, depending on one's individual background and experience. *Webster's Collegiate Dictionary* (10th edition) defines *benchmark* as "a point of reference from which measurements may be made; something that serves as a standard by which others may be measured." Although this definition primarily refers to a surveyor's mark or point of reference, the term has also been used in the context of setting and measuring standards related to product characteristics and organizational performance. In the early 1970s, the Xerox Corporation (and others) promoted the concept of benchmarking as a "business practice." According to Camp, benchmarking can be defined as "the continuous process of measuring products, services, and practices against the toughest competitors or those companies recognized as industry leaders."[1] Balm provided a more comprehensive definition, whereby benchmarking is "the ongoing activity of comparing one's own process, product, or service against the best known similar activity, so that by challenging attainable goals a realistic course of action can be implemented to efficiently become and remain the best of the best in a reasonable time."[2] This definition includes the element of *time,* which is critical if improvement is to be made in a competitive manner.

In regard to system engineering, there have been a number of benchmarking studies, and a few companies that practice the concepts and principles described throughout this text have implemented an active benchmarking effort internally.[3] The emphasis in most of these instances has been oriented directly to organizations and the processes that they use in accomplishing their day-to-day functions. Although this is appropriate, care must be taken to first define the company's objectives in terms of *product output* and then address the organizational characteristics that are considered to be essential in order to successfully meet the overall product goals. It is often tempting to launch into an evaluation of organizational effectiveness, employing some measures that may or may not be relevant to the ultimate objectives, and then initiating changes. Such changes may turn out to provide negative results because the proper goals were not defined at the beginning.

As shown in Figure 8.1, the general approach to benchmarking commences with the development of a plan for implementation (see block 2). This is based on a definition of the organization's objectives as they pertain to product goals. Product goals may be specified in terms of the technical performance measures (TPMs) for a given system, or some equivalent set of measures for one or more products. For example,

[1]Robert C. Camp, *Benchmarking—The Search for Industry Best Practices That Lead to Superior Performance* (Milwaukee: ASQ Quality Press, 1989).

[2]Gerald J. Balm, *Benchmarking: A Practitioner's Guide for Becoming and Staying the Best of the Best,* (Schaumburg, IL: QPMA Press, 1992).

[3]Kenneth Jones, *Benchmarking Systems Engineering in United States Industry,* Systems Engineering Design Laboratory, Virginia Poltechnic Institute and State University (Blacksburg, VA: 1994). Forty individuals from 21 different companies who had previously indicated that they were implementing the concepts and principles of systems engineering participated in this project study. For additional references relative to the application of benchmarking in system engineering, it is recommended that you research the literature contained within the *Proceedings* from the annual conferences sponsored by the International Council on Systems Engineering (INCOSE), Seattle, Washington.

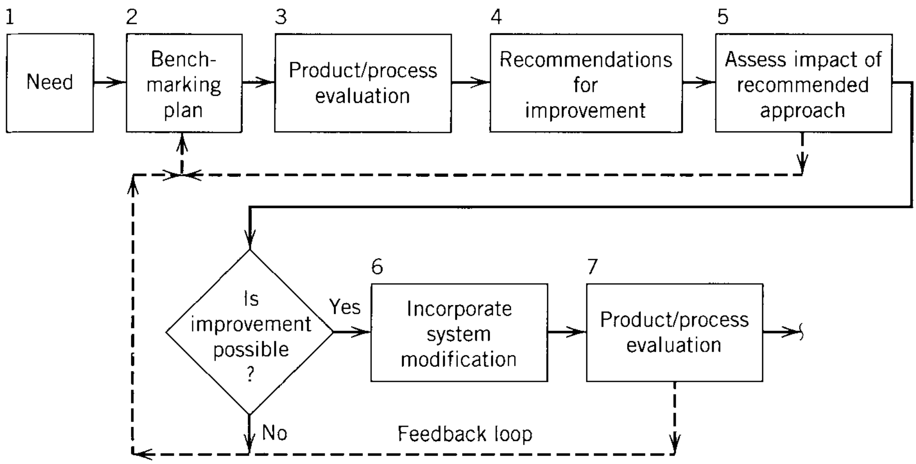

Figure 8.1 Benchmarking process.

Figure 2.10 identifies the TPMs for a system/product that resulted from a quality function deployment (QFD) analysis. Assuming that the quantitative requirements in the third column represent current status and that the immediate objectives include progressing to the requirements specified in the second column, then a plan needs to be developed covering the steps that must be accomplished in progressing from the current status to the level of performance ultimately desired. These steps relate to the organizational structure and the processes that are currently being implemented to support the product-oriented goals. For the purposes of this text, these include the system engineering functions and tasks described in Section 6.2.2.

In block 3 of Figure 8.1, one of the first steps is to define what is meant by *system engineering,* what is included, and what tasks must be accomplished in order to properly implement the concepts and principles described herein as they pertain to the product goals. This may lead to the development of a questionnaire, or series of checklists, used to facilitate the evaluation process. An assessment of the current processes is accomplished, possible problem areas are noted, recommendations for process/product improvement are developed (block 4), the potential impact of these proposed changes is assessed (block 5), and, if feasible, modifications are incorporated as appropriate. This may be a continuous process until the desired level of performance is attained.

Figure 8.2 illustrates a benchmarking plan showing the current status in terms of some level of performance, the status of the major competition, and the desired objective. It can be assumed that the competitor is also involved in a benchmarking effort and has established some higher-level goals. Thus, for the system/product in question, a plan must be developed that will enable one to follow Path A–B in lieu of Path C–D.[4]

[4]It should be reemphasized that the first step is to establish organizational "capability" goals, which stem from the projects (and their respective requirements) that the organization wishes to take on, and then to identify the steps required to develop the organization so that it can respond to such goals both effectively and efficiently.

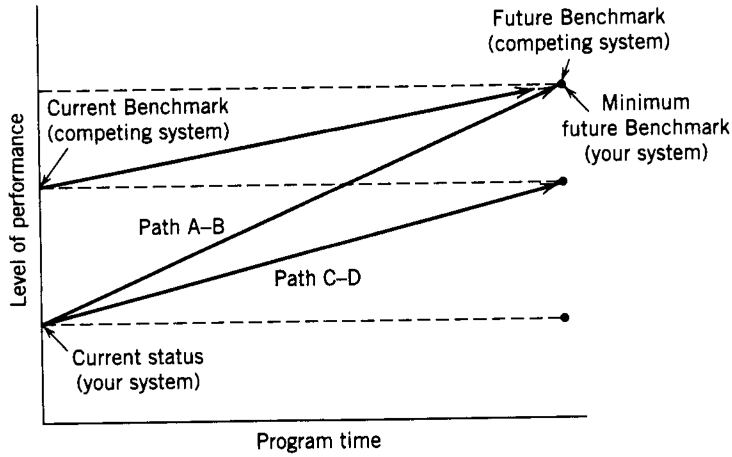

Figure 8.2 Benchmarking.

8.3 EVALUATION OF THE SYSTEM ENGINEERING ORGANIZATION

Certain company/agency/institution goals having been established, the next step is to discover the extent to which the system engineering organization has progressed toward meeting these goals; that is, the measure of the organization's capability to meet the desired level of performance. Given the objectives of system engineering and the recommended tasks that must be performed, there are some questions that should be addressed: To what extent is the organization completing these tasks effectively and efficiently? Does the management understand the principles and concepts of system engineering? Is there a commitment from the top down toward the implementation of the system engineering process? If so, what policies are currently being implemented to support this? Have standards, measurable goals, and the appropriate processes been established for the successful accomplishment of system engineering objectives? Has the organization developed a plan for continuous improvement?

Although there are many questions of this nature that can be asked, the objective is to determine the organization's *level of maturity*, where it may "fit" in the hierarchical structure as compared with other organizations functioning in a similar area of activity, and where there are weaknesses that need to be addressed. In other words, although the benchmarking process aids in establishing specific goals, there is a need to develop a model to assist in the evaluation of an organization's current capability.

In response, there has been a concerted and continuing effort since the late 1980s to develop a model that will address the organizational assessment issue. Although there have been numerous models used to varying degrees through the years, a series of recently developed specific projects/models is noteworthy. Through the early efforts of the Software Engineering Institute (SEI) at Carnegie Mellon University, a process improvement model oriented to software development, Software Capability Maturity Model (SW-CMM), was first introduced in 1989. As a result of experience and continuous upgrading, Version 1.1 of SW-CMM was released in 1993. Based on this experience, and through the combined efforts of many in industry, government, and academia, the System Engineering Capability Maturity Model (SE-CMM) was developed and released for use in 1994.[5] At the same time, and with the coordination and support of the International Council on Systems Engineering (INCOSE), the Systems Engineering Capability Assessment Model (SECAM) was released in 1994.[6] These two models were then successfully merged into EIA/IS-731 in 1998 as a result of a collaborative effort involving EIA (Electronic Industries Alliance), EPIC (Enterprise Process Improvement Collaboration), and INCOSE.[7]

Subsequent to the initial release of EIA/IS-731, there have been a number of individual efforts to develop comparable models for different purposes. In addition to the models covering software development and systems engineering, an effort was initiated to develop a model for *Integrated Product and Process Development* (IPPD). Further, there have been efforts to address other critical areas where a measure of organizational maturity is desired. Given the trend relative to developing a series of different models for individual purposes, an effort was initiated in 1998 to study the feasibility of developing one comprehensive "model" that would represent an "integrated" approach and combine the capabilities of the SW-CMM, SE-CMM, SECAM, and the IPPD model. The result of this effort has produced a new product, Capability Maturity Model Integration (CMMI). The objective is to eliminate the "stovepipe" models and to adapt CMMI as the ultimate measurement tool for the various areas of concern.[8]

To get some idea of the detailed approach for implementation, given that the emphasis throughout this text is on "systems engineering," it would be appropriate at this point to consider the Systems Engineering Capability Model (SECM), discussed in EIA/IS-731. One of the first steps in its development was, of course, to define the goals and objectives of a system engineering organization. Having accomplished this, essential systems engineering and management tasks that an organization must perform to ensure a successful effort were identified and included in three basic focus-

[5]Software Engineering Institute (SEI), *A Systems Engineering Capability Maturity Model (SE-CMM)*, Version 1.1, SECMM-95-01, (Pittsburgh, PA: Carnegie Melon University, 1995).

[6]A good reference that provides a historical basis for the SECAM and its applications is B. A. Andrews and E. R. Widmann, "A Synopsis of Metrics and Observations from Systems Engineering Process Assessments Conducted Using the INCOSE SECAM," in *Proceedings of the Sixth Annual International Symposium of the INCOSE*, Vol. 1 (Seattle, WA: INCOSE, 1996), p. 1071. Additional references are included in the *Proceedings* from earlier INCOSE symposia.

[7]GEIA (Government Electronics and Information Technology Association), EIA/IS 731: *Systems Engineering Capability Model (SECM)*, Washington, DC, 2001 (web site: http://www.geia.org/sstc/G47/page6.htm, October 2001).

[8]A good reference covering the history and background leading to the development of the CMMI is *Systems Engineering: The Journal of the International Council on Systems Engineering* Vol. 5, no. 1 (2002) published by John Wiley & Sons, Inc. New York. There are a series of articles in this *Journal* issue that deal with CMMI, the status of EIA/IS-731, and related topics. Further, there are a number of issues of *CrossTalk: The Journal of Defense Software Engineering*, published by the Software Technology Support Center, Hill AFB, Utah, that discuss the CMMI model and objectives.

FOCUS AREA CATEGORIES		
TECHNICAL	MANAGEMENT	ENVIRONMENTAL
• Define Stakeholder and System-Level Requirements • Define the Technical Problem • Define the Solution • Assess and Select • Integrate System • Verify System • Validate System	• Plan and Organize • Monitor and Control • Integrate Design Disciplines • Coordinate with Suppliers • Manage Risk • Manage Data • Manage Configurations • Ensure Quality	• Define and Improve the System Engineering Process • Manage Competency • Manage Technology • Manage System Engineering Support Environment

Figure 8.3 SECM Focus areas and categories (EIA/IS-731).

area categories; that is, a *technical category focus area,* a *management category focus area,* and an *environment category focus area.* Establishment of the focus-area categories then led to the identification of specific *focus areas,* which led to *themes,* which led to a description of specific *practices.* The results of this progression are summarized in a presentation of the major topics shown in Figure 8.3.

Given a description of the desired practices, the next step was to identify different *capability levels* (levels of "maturity"), or the degree(s) of capability an organization should strive to meet, evolving from current capability to a future level, indicating growth potential. Six capability levels were established and related to individual focus areas. A focus area includes a list of practices describing the activities that an organization must successfully perform. In Figure 8.4, the levels of capability (from "Level Zero" to "Level Five") are identified as *initial, performed, managed, defined, measured,* and *optimized.* These levels are supported by a description of specific practices that are desired in order to meet the requirements for a given level. The objective, of course, is to progress to Level Five.

In applying this model in the appraisal (or assessment) of an organization's capability, there are different phases: *preassessment, on-site assessment,* and *postassessment.* During the preassessment phase, it is necessary to solicit management support of the organization to be evaluated and to develop the process for evaluation. Included in this phase is the development of a rather extensive questionnaire (which contains many different questions for the EIA/IS-731 requirement, or a minimum of 40 questions pertaining to Level One, 91 questions for Level Two, 156 questions for Level Three, 56 questions for Level Four, and 83 questions for Level Five).[9] The "on-site assessment" phase includes the following steps: administering the questionnaire, analyzing the results, developing some additional exploratory questions, conducting in-

[9]S. Alessi, "A Simple Statistic for Use with Capability Maturity Models," *Systems Engineering: The Journal of the International Council on Systems Engineering* Vol. 5, no. 3 (2002): 242–252 (published by John Wiley & Sons, Inc. New York).

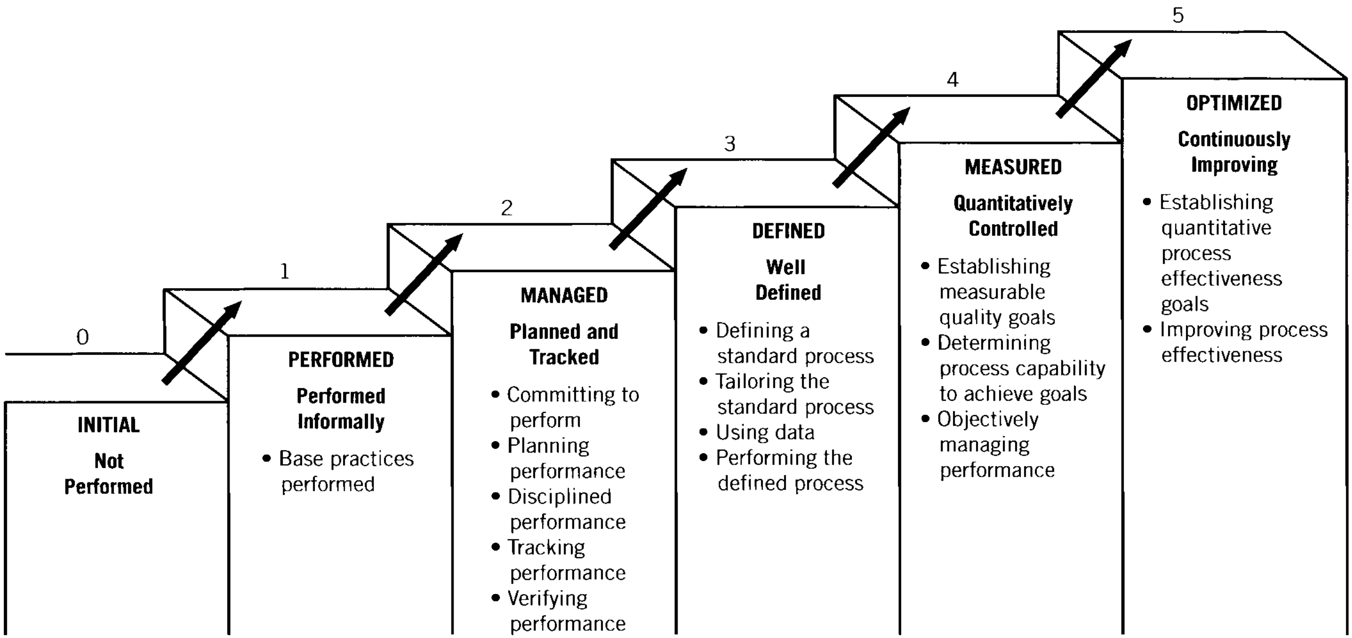

Figure 8.4 Improvement path for system engineering process capability.

terviews with focus groups, analyzing exploratory data, summarizing the results and coordinating with management, and preparing the final evaluation report. This phase is usually conducted during a one-week period, by a team of three to five people working with a combination of department managers, project leaders, and workforce practitioners, and results in rapid feedback and minimizing any impact on internal projects and the day-to-day scheduled work. The postassessment phase involves management briefings and the preparation of a plan for future action as required.

The results of the assessment, utilizing the SECM, should include a summary chart/graphic showing the different focus areas and the degrees to which each has achieved a given "level of capability." In Figure 8.5, it can be seen that Focus Area 1 in the Managed category has achieved "capability" at Level 3, and that Focus Area 2 (in the same category) is only at Level 1. Given these results, the final assessment report (and plan for future action) should include some specific recommendations for improvement, particularly in regard to Focus Area 2, and the action(s) that need to be initiated in order to progress to the next higher level. The objective is, of course, to make progress in all of the focus areas with the proper balance being achieved across the board.

The preceding description provides only a rough idea as to the objectives and content of the Systems Engineering Capability Model (SECM). For more in-depth coverage, a detailed review of EIA/IS-731 is recommended. Relative to the future, although this model will, in all probability, continue to be applied in selected areas and oriented to the assessment of a systems engineering organization as an entity, acquiring a good understanding of the Capability Maturity Model Integration (CMMI) is also recommended, as this is a more comprehensive model and gaining in popularity.

In comparing the SECM with the CMMI, it is clear that the basic architectures are quite similar.[10] The SECM includes focus areas and categories; the CMMI takes the same basic approach, although the specific topics and nomenclature are different. In Figure 8.6, there are four Process Area Categories: process management, project management, engineering, and support. Within each of these categories, there are a number of specific Process Areas, for which detailed questions have been prepared for purposes of assessment. Note that the activities in CMMI are much broader in scope than those in SECM. In regard to "levels of capability," the CMMI also has established six levels (i.e., "Level Zero" to "Level Five"), including *incomplete, performed, managed, defined, defined, quantitatively managed,* and *optimizing.*

For purposes of assessment, the Standard CMMI Assessment Method for Process Improvement (SCAMPI) is accomplished through the application of questionnaires, local visits and interviews, and the like. Specific scoring rules for each capability level are used, and the highest resulting score reflects the "level of capability" attained for the process area being evaluated. In any event, the overall approach here is similar to that described earlier for SECM.

It should be noted that the development effort for CMMI continues and there are

[10] I. Minnich, "EIA/IS-731 Compared to CMMI-SE/SW," *Systems Engineering: The Journal of the International Council on Systems Engineering* Vol. 5, no. 1 (2002) 62–72 (published by John Wiley & Sons, Inc.). New York

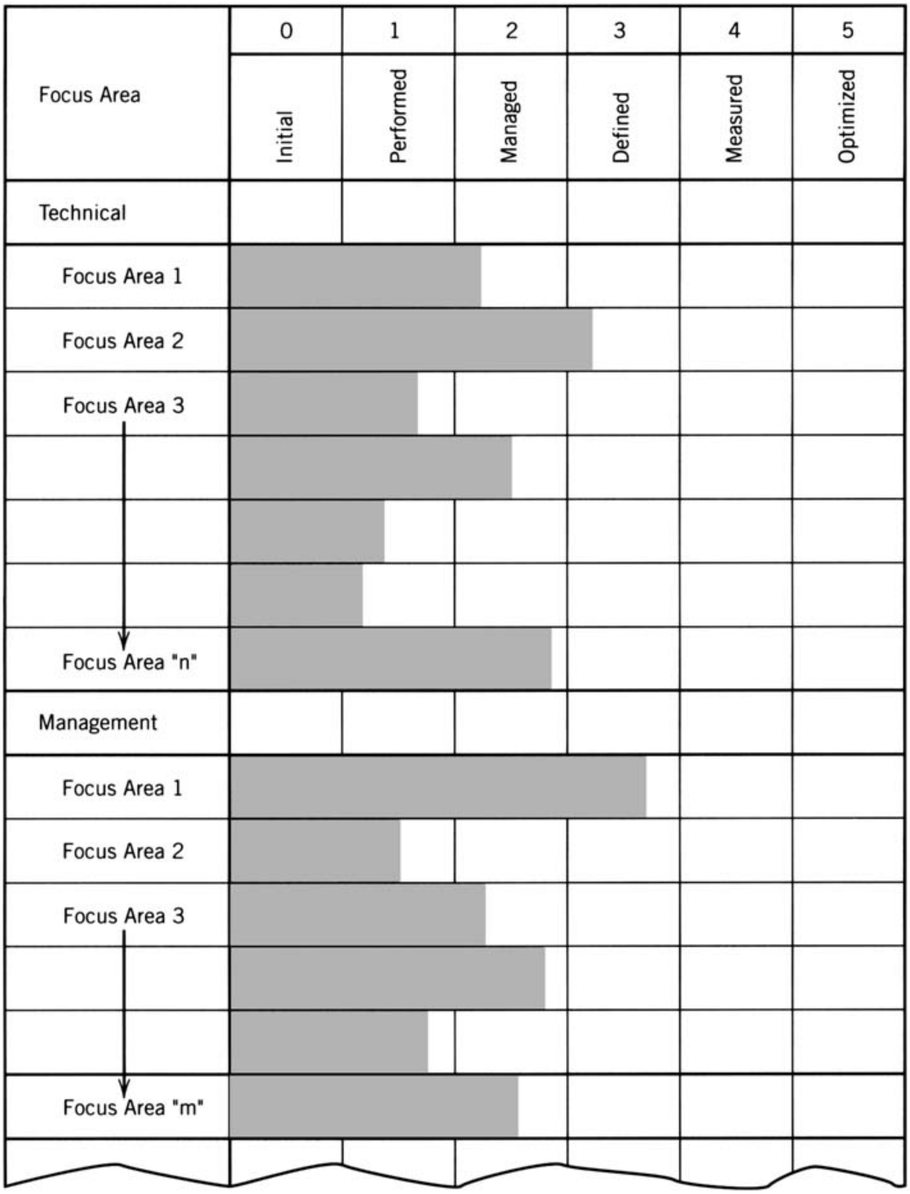

Figure 8.5 Focus area capability assessment.

PROCESS AREA CATEGORIES			
PROCESS MANAGEMENT	PROJECT MANAGEMENT	ENGINEERING	SUPPORT
• Organizational Process Focus • Organizational Process Definition • Organizational Innovation and • Deployment	• Project Planning • Project Monitoring and Control • Supplier Management • Integrated Project Management • Risk Management • Quantitative Project Management	• Requirements Management • Requirements Developement • Technical Solution • Product Integration • Verification • Validation	• Configuration Management • Process and Product Quality Assurance • Measurement and Analysis • Decision Analysis and Resolution • Causal Analysis and Resolution

Figure 8.6 CMMI process areas and categories. *Source:* I. Minnich, "EIA/IS-731 Compared to CMMI SE/SW," *Systems Engineering: The Journal of the International Council on Systems Engineering* Vol. 5, no. 1 (2002), Table II. (Published by John Wiley & Sons, Inc.)

additional critical areas of activity that are being considered for inclusion (as this text goes to press). Thus, it is recommended that the reader pursue additional research in this area to ensure currency.[11] This is particularly important, as the CMMI will likely be applied in the evaluation of all program organizations in the future. In any event, it is believed that the approach described throughout this section is excellent and certainly valid in the evaluation of a systems engineering organization.

8.4 PROGRAM REPORTING, FEEDBACK, AND CONTROL

The discussion in the earlier sections of this chapter applies primarily to the evaluation of a systems engineering activity operating within a large producer's organization (i.e., the prime contractor). As with any activity, the processes described in Sections 8.2 and 8.3 must be tailored to the specific organization being evaluated. As shown in Figure 7.1, the successful implementation of system engineering objectives depends not only on the producer's activities, but also on the related activities of the customer's organization and the activities of the various major suppliers participating in the program in question. Thus, there are both "upward" and "downward" impacts that must be considered.

In regard to an SECM, CMMI, or equivalent evaluation, the results highlight specific areas of weakness and where improvements in the applicable processes can be realized. With potential areas for improvement having been identified, there are two steps that need to be addressed:

[11]For further information, contact Carnegie Melon University, 14742 Beach Boulevard, #405, La Mirada, CA 90638 (e-mail: ibm@sei.cmu.edu).

1. Determining ways for improvement of internal processes *within* the system engineering organization.[12] This encompasses evaluating alternative methods of doing business, determining the requirements for changing the existing procedures and processes, and assessing the impact of such changes on the other processes. A change in any one process should not have a negative impact on any other process.

2. Determining the possible impact(s) of changes in the processes being implemented by the systems engineering organization on any *external* and related organizational structures—the customer, other organizational groups within the producer's operation, major suppliers, and so forth. The proper environment must be established within the overall organizational infrastructure for the proposed changes described in item 1 to result in an improvement.

Proposed changes within the system engineering organization cannot be initiated in a vacuum. There must be a mutual commitment throughout the organization and, in particular, by the program manager and his or her staff. In any case, there must be a vehicle through which organizational improvement can be initiated.

Given the approval and incorporation of a "change" (or group of changes), the revised processes/procedures must be documented and reported and must serve as a baseline for the next organizational evaluation. Although there is no established frequency of evaluation, it is recommended that the approach and procedures discussed herein be included as a "continuing activity" within the overall spectrum of system engineering organization activities.

8.5 SUMMARY

In approaching a subject such as "system engineering management," it is essential to first address the activity that is to be managed. The first five chapters of this text accomplish this by describing system engineering principles and concepts, the system engineering process, and supporting requirements as they apply in the design and development of major systems. The next step is to cover the necessary functions/tasks that must be implemented in order to realize the objectives described in the beginning. Thus, Chapters 6, 7, and 8 discuss the necessary steps for implementation; that is, the *planning* for system engineering, the *organization* for system engineering, and the subsequent *evaluation* (and *feedback*) in regard to how well we have planned from the beginning and how well we have performed in the organization and follow-on implementation of system engineering requirements. Accomplishing planning and organization activities alone, without having the benefit of subsequent evaluation and feedback, constitutes only part of the overall process and is certainly inhibiting when it comes to capturing the experiences from the past and realizing growth for the future.

[12]In determining ways for improvement, reference should be made to the "benchmarks" that were established in Section 8.2. The objective in initiating change is to meet (if not exceed) a specified benchmark goal. In addition, one needs to assess the impact of change in terms of risk and the Risk Management Plan (refer to Section 6.7). The goal is, of course, to reduce risk as a result of change.

This chapter emphasizes the importance of evaluation and feedback. Much of the material included herein addresses a popular set of models being developed and applied in the evaluation of system engineering organizations today (i.e., SECM and CMMI). As we evolve further into the future, there will (in all likelihood) be a new set of tools available for the purposes of evaluation. In any event, the important issue is to ensure that there is an *evaluation and feedback capability* built into any type of a system engineering program.

QUESTIONS AND PROBLEMS

1. Why is system evaluation and feedback important? Describe some of the benefits that can be realized through the implementation of such a capability. What is likely to occur should such a capability not be implemented?
2. What is meant by *benchmarking?* If you were assigned to develop and implement a benchmarking capability for your program (as program manager), what steps would you take in accomplishing this assignment?
3. In developing a benchmarking capability, what specific factors would you, as program manager, select in attempting to establish the appropriate goals for your program?
4. Review the literature pertaining to the SECM and CMMI tools and their application. What are the basic objectives of each (how do they differ)? What factors are measured? Briefly describe the steps to be followed in the implementation of each.
5. Assuming that you, as manager of the System Engineering Department, have just completed an assessment of your organization utilizing the SECM approach, what steps would you initiate next?
6. Assume that you, as manager of the System Engineering Department, need to gain some good visibility as to how well your organization is performing. What type of reports (or reporting requirements) would you require of your organization? How often would they be required?
7. Assume that you, as manager of the System Engineering Department, are dependent on the performance of a number of major suppliers. What steps would you take (and what should be included) in establishing the requirements for the evaluation of the suppliers?
8. As part of a supplier evaluation effort, you are planning to visit a major supplier's facility. What would you do in preparation, and what information would you solicit during the on-site visit?
9. In your opinion, how often should the evaluation of a system engineering organization be accomplished? Why?

10. What should be considered in recommending process changes resulting from an evaluation?

11. Refer to Figure 6.33 and Appendix E. Develop a supplier checklist for the purposes of evaluation (prepare the checklist in the format shown in Figure 6.33 and provide a breakout of factors for each item in your checklist, as illustrated in Appendix E).