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Carnegie-Mellon University
Software Engineering Institute

The Subject Matter of Process Improvement: A Topic and Reference Source for Software Engineering Educators and Trainers

Rosalind L. Ibrahim

Iraj Hirmanpour

May 1995

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Review and Approval

This report has been reviewed and is approved for publication.

FOR THE COMMANDER

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SEI Joint Program Office

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We welcome the views of our readers. To send us your inputs for enhancement, improvement, and further work in the area of process improvement, please contact

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The Subject Matter of Process Improvement

A Topic and Reference Source for Software Engineering Educators and Trainers

Abstract: This report provides a high-level topical overview of what can be taught or learned about process improvement. The subject matter is presented within a general framework of six major topic areas, which are described and divided into annotated subtopics. The relationships and application of the subject areas are explained in the context of process improvement activities. Topic areas range from process and process improvement concepts to tools, techniques, teamwork, and interpersonal skills.

The purpose of this report is to assist software engineering educators and trainers in selecting topics for curricula or training programs. It may also be used to guide self-study in this area. Pointers to detailed sources of information are given, but no in-depth information is otherwise provided for the topic areas. Consequently, this report is not suitable for use by itself as a means of learning the details of how to do process improvement.

"Over the long run, superior performance depends on superior learning."
—Peter Senge

1 Introduction

Today's software organizations are striving to remain competitive and healthy. One path to providing a competitive edge lies in establishing an organizational culture driven by quality aspirations and continuous improvement. For such organizations it is necessary that software engineers and managers are properly equipped to implement improvements and changes. The challenge for educators and trainers is to ensure that adequate knowledge and skills are acquired so that organizations can make rational decisions and carry them out effectively, i.e., to ensure that the organization possesses a solid base of competency in process improvement.

Software engineering organizations tell us that they encounter obstacles to process improvement such as the following [Ibrahim 93a]:

- "lack of awareness and understanding"
- "inadequate training"
- "misunderstanding of the importance of process improvement"

Some of the needs and recommendations we have heard include the following:

- "We must educate people on the process so that they understand why we're doing this as opposed to just getting a 'good grade.'"

- "Educate/train people from the top down and from the bottom up."
- "Get process improvement exposed more in commercial/educational organizations."
- "Include process improvement in formal software education curriculum."

We hope to help overcome these obstacles and start meeting these needs by examining what process improvement education and training entails.

Process improvement is an emerging topic in software engineering education and training. It is so new that the body of knowledge is still evolving, yet there are considerable data available regarding what one might need to know. They can be found scattered in various courses, tutorials, workshops, documents, articles, curricula, standards, texts, etc. They are known by those who are working on process improvement in the field, but they have not been compiled to help software engineering educators and trainers offer the requisite knowledge and skills their students need.

Piecemeal education and training will only offer piecemeal solutions to the quality problems we are facing in the software industry. By providing an overview of the topics that make up process improvement, we hope to offer software engineering educators and trainers a broad context from which they can select the most appropriate topic areas for their particular environments.

This document compiles and describes the subject matter of process improvement in the hope that it will provide guidance for the design and implementation of comprehensive process improvement education and training for the software engineering managers and practitioners of today and tomorrow.

1.1 Background

Several factors have motivated the preparation of this report. In 1992-1993, a survey was conducted by the SEI to assess the needs of the software community regarding Capability Maturity Model for Software (CMM℠)* -based education and training [Ibrahim 93a]. Survey results indicated the need for more focus and direction regarding process improvement education and training, and the need to remove barriers to learning.

At the 5th Software Engineering Process Group National Meeting [SEPG 93], several papers concentrated on software process improvement education and training and a well-attended Birds-of-a-Feather (BoF) session on Education and Training commenced with a plea for "the big picture" of what must be taught [Ibrahim 93b]. Another BoF session was held at the 7th Conference on Software Engineering Education (CSEE) [Radice 94] where the exchange involved academics as well as industry and government educators. That session reverberated the need for process education in universities.

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The development of this report began in April 1994. Shortly thereafter more than 50 people at the 6th SEPG Conference [SEPG 94] signed up expressing interest in this endeavor. Interchanges continued at the 1994 SEI Symposium where a focus group of process improvement educators and trainers provided input to this report [Focus 94]. The Pittsburgh SPIN (Software Process Improvement Network) meeting in October 1994 was a facilitated discussion of successes and barriers to process improvement, and the highest priority barriers reported by that group were "Lack of understanding and knowledge about software process improvement" and "concepts aren't taught at universities" [Ibrahim 94].

This document contains the beginnings of what the software community has been seeking, in the hope that further work involving partners from industry, government, and academia can complete the picture and build an infrastructure equipped to provide education and training in process improvement.

1.2 Overview

This report describes the subject matter of process improvement. It is an initial compendium of topic areas that make up this aspect of software engineering endeavor.

The report is organized as follows:

This section presents audience, usage, expectations, and scope. Section 2 describes the method used in preparing this report. An overview of the subject matter framework and topic breakdown is provided in Section 3. Sections 4-9 describe the topic areas: Process Fundamentals, Process Improvement Fundamentals, Process and Process Improvement Management, Culture Change, Tools and Techniques, and Pervasive Supporting Skills. Conclusions, including tailoring and delivery considerations, are provided in Section 10.

Process improvement includes improvement of the educational process itself, and a separate appendix presents best practice recommendations from selected models and standards.

1.3 Audience and Usage

This report is primarily intended for use by educators and trainers in academic and industrial settings. Other possible audiences include managers, members of software engineering process groups (SEPGs), change agents, and practitioners concerned with software process improvement. We hope that any members of the software community motivated to learn about and carry out process improvement can find information that will help them instill an improvement philosophy in their own work and in their organizations.

1.3.1 Academic Usage

In an academic setting, this work offers guidance in meeting the following educational goals:

- to provide a specialty concentration of knowledge and skills in software process improvement

- to produce engineering managers and software engineers who are equipped to contribute to process improvement

The following steps are typically carried out to meet these goals:

- Decide the content of the subject matter area and describe it.
- Design a curriculum (consider subsets of the content appropriate for a particular program, organization, target population; ordering, relationships among topics and subtopics; packaging, etc.).
- Develop/acquire courses.
- Deliver.
- Evaluate and revisit the above steps.

This document concentrates on the first step—deciding and describing the content of the process improvement subject matter area. The academic audience will use this subject matter description to design curricula or to develop courses.

1.3.2 Industry Usage

In an industrial setting, this work offers guidance in meeting the following goal:

- to provide knowledge and skills to enable an organization to improve its process capability

Typically an organization might carry out a knowledge and skills analysis in order to derive data about the knowledge and skills required for tasks performed by the organization's business functions [Curtis 94].

This report may be used as a high level guidance profile of knowledge and skills pertaining to the specific business function of process improvement. The subject matter description is based on typical tasks that might be carried out in any organization, and it is intended to be tailored by the industrial audience for different needs and contexts. The report suggests topic areas that might be candidates for process improvement education and training or for training in primary competencies as defined in Curtis [Curtis 94].

1.3.3 Self-Study Usage

For a self-study user of this report, the reader will be introduced to the breadth of topics and subtopics of process improvement. No topic is dealt with in sufficient depth to enable mastery because that is not the intent of this report. The reader will get an overall view of the material and will be given extensive references for the pursuit of particular topics of interest.

1.3.4 Sample Usage

Draft versions of this report have been used in the following ways:

- to prepare course outlines
- to derive course bibliographies

- to design a set of three university courses
- to prepare lectures on selected topic areas
- to help identify specific training needs
- to profile potential training areas
- to prepare an executive briefing

1.4 Expectations

1.4.1 What the Report Contains

A reader of this report can expect to embark on a tour through the topic areas that make up process improvement. This tour is annotated at the major topic area level and for major subtopics. Relationships between the topic areas are explained. Beyond that, key areas within subtopics are either listed, very briefly annotated, or noted by way of examples. The bibliography provides references for further information.

Thus the reader will acquire a general knowledge of the subject matter of process improvement and an awareness of the broad range of topics in the field.The report presents the topics and shows: how they are related, when they are used, why they are important, and where to find more information.

1.4.2 What the Report Does Not Contain

This report does not offer a simple solution to an immediate problem. It does not dictate what topics must be taught or learned in any particular context, although some tailoring considerations are provided. It is not possible to derive an in-depth knowledge about any of the subject matter from reading this document.

It is left to the reader to make judgements, to extract and package topic areas in specific domains, and/or to pursue learning goals by means of further study.

1.5 Scope of Process Improvement

The scope of process improvement for this report includes

- process improvement at organizational, process, and individual levels
- concepts and theory about process improvement technology (education) as well as skills in applying this technology (training)
- people and cultural aspects of the process improvement environment

Please note that much of the information included pertains to "general" process improvement concepts and skills that could be applied to improve any process, but the focus is on their application in software engineering process improvement.

The scope excludes

- elaboration of subject matter regarding process areas that are already well described, [such as product engineering (requirements analysis, design, coding, testing, and maintenance), software configuration management, software quality assurance, software project management] except in the context of more generic process improvement
- elaboration of subject matter in areas that are judged to be more product oriented than process oriented

We recognize that competency in these software engineering areas is essential and we refer the reader to other sources [Ford 91], [Shaw 89], [PMBOK 94] for descriptions of software engineering topic areas, academic programs, textbooks, journals, general software engineering reference materials, and general project management practices.

2 Method Used

2.1 Data Gathering

The basic approach to compiling this work involved collecting data from the following categories of sources:

- SEI courses, workshops, tutorials, services, and documents relating to various aspects of process improvement
- selected literature, including published standards, certification, and professional society publications
- customer views, including experiences, viewpoints, and documents provided by change agents, educators, and trainers in industry, government, and academia

The strategy regarding selection of these sources was motivated by the following:

- to abstract and coalesce SEI process improvement guidelines and materials into one general subject matter framework
- to augment that basis with selected widely adopted standards and approaches to process improvement
- to include a full range of topic areas covering the breadth of the area
- to provide selected (but not exhaustive) examples of process improvement strategies being used in the field
- to validate and augment the subject matter coverage with viewpoints and insights of practitioners
- to include extensive references to provide more examples and details of the subject matter

Accordingly, the data were collected through a variety of approaches including informal questionnaires, focus groups, and course material/document review. (See Appendix B for a description of customer data sources.)

Whereas data reported from the field contributed to this document, no formal industry-wide job analysis was performed in compiling this information (e.g., [IEEE-CS/ACM 94], [Westfall 93], [ETS 94]). Nor was a detailed knowledge and skills analysis carried out involving first hand study of the roles, tasks, and capabilities required for different process improvement jobs in specific organizational contexts. (See Curtis [Curtis 94] for guidance on how this might be accomplished.)

For this compilation, we extracted the knowledge and skills already embedded in several widely acknowledged software process improvement models, standards, practices, and approaches. The assumption is that published approaches advocated by specific organizations and process improvement topics chosen by experts, educators, and trainers explain the knowledge and skills that are necessary—or could be useful generically—to carry out process improvement.

2.2 Data Analysis and Structuring

An initial top-down framework for assembling the subject matter was established and then revised as data were gathered through a bottom-up data collection process.

The intent is to present the topic areas so that the information is in a useful form for educators and trainers to extract, structure, tailor, and evolve for their own audiences. Thus subject topics needed to be cohesive enough to comprehend as a unit, and modular enough to enable combination with other topics or inclusion in more traditional course offerings.

Another analysis concern was the degree of granularity that would be most useful in a report like this. Each unit or topic area might be expanded or contracted in different environments or for different needs. The intent is to provide sufficient content to guide educators and trainers in setting up programs, and give references that offer additional detail.

2.3 The Review Process

This report was reviewed internally for early drafts, and both internally and externally for later versions. A structured review session was held on an intermediary draft and the final draft underwent another internal review process. (See Appendix B for reviewer participation.)

3 Topic Areas

3.1 Describing Knowledge and Skills

3.1.1 Knowing and Doing

When describing knowledge and skills, we are describing what people know and what people do. It is possible to know something and not do anything with it. It is also possible to do something and not know much about it. What we are trying to delineate here are those essentials that must be **known** in order to **do** process improvement in a rational way.

This report offers essential knowledge that we hope will improve conventional thinking, practice, and organizational decision making about process improvement.

Several factors influence knowledge use (technology transfer) and change, and several models have been proposed delineating these factors. Some of these approaches will be presented in Section 7 (Culture Change). One pervasive theme throughout technology transfer literature is that there must be the ability to carry out the change: there must be education, training, and learning. Thus the challenge to educators, trainers, and change agents is to transfer this subject matter to software engineering managers and practitioners for its effective use in practice.

3.1.2 What is Knowledge?

One definition of knowledge [Glaser 83] states that knowledge includes

- facts, truths, and principles associated with professional practice
- information or understanding based on validated, broad experience
- reliably identified exemplary practice including unusual knowhow
- information certified as valid by applying criteria or tests
- findings of validated research

One might ask, does such a body of knowledge exist for software process improvement? As software evolves from a craft to an engineering discipline this knowledge is emerging, and as process improvement gains more and more momentum throughout the software community, methods and experiences are becoming validated and documented. We are attempting to identify that emerging body of knowledge. Because the field is so new, we are also including selected software process improvement practices and methods that are still in the piloting or developmental stage.

Another view of knowledge and skills is embodied in Bloom's *Taxonomy of Educational Objectives* [Bloom 56]. This taxonomy delineates a hierarchy of six increasingly difficult levels of achievement:

- knowledge: this level is mainly concerned with terminology and facts; information can be recalled, but there is no deep understanding.

- comprehension: materials can be used in a narrow sense, can be rephrased, or summarized but not extended or related to other ideas.
- application: abstractions can be applied in particular situations; principles, techniques, tools, and methods can be remembered and applied.
- analysis: the parts and relationships among elements can be recognized and identified.
- synthesis: elements can be combined to produce something new.
- evaluation: value judgments can be made; improvements can be recognized; suggestions for innovation can be made.

This taxonomy puts "improvement" at the most complex achievement level. The hierarchy also implies that each level builds on the mastery of concepts and skills internalized at lower levels of achievement. The presentation that follows intends to span Bloom's taxonomy. In that sense it describes the competency an organization needs in order to master process improvement.

3.1.3 Competency

Competency enables an individual or an organization to carry out activities that will achieve desired outcomes. It can be considered a combination of knowledge, skills, and personal attributes that contribute to effective performance. Knowledge is typically gained by education, while skills are gained by training, and attributes are gained by experience.

One approach we take in the report is to describe knowledge, skills, and attributes in the context of process improvement activities; activities are described, and then examples of relevant knowledge, skills, and attributes extracted.

3.2 The Framework

We evolve the subject matter by starting with concepts and leading to their application in process improvement activities. Then we describe tools, techniques, and skills that can be used to help carry out those activities. This *know*, *do*, *use* framework is illustrated in Table 1.

Table 1: Framework for Describing Process Improvement Subject Matter

Understand concepts	**KNOW**: Process Concepts **KNOW**: Process Improvement Concepts
Apply concepts, make choices	**DO**: Process and Process Improvement Management **DO**: Culture Change
Use tools, techniques, skills	**USE**: Tools and Techniques **USE**: Pervasive Supporting Skills

Although we do not prescribe a specific ordering of topics and subtopics for delivery of this material, we have found this to be a logical, rational approach to understanding the subject matter.

We embellished this framework into the topic and subtopic areas portrayed in Table 2.

Table 2: Process Improvement Topics and Subtopics

Category	Description	Topic/Subtopic References
KNOW: **Process** **Fundamentals**	These are essential concepts that must be known or comprehended regarding the nature of a process. They include process maturity, development, enactment, modeling, definition, and measurement concepts. Software engineering process areas and processes are included as fundamental knowledge.	Section 4: Process Fundamentals 4.1 General Concepts 4.2 Process Maturity Concepts 4.3 Process Development and Enactment Concepts 4.4 Process Modeling Concepts 4.5 Process Definition Concepts 4.6 Software Process Measurement 4.7 Software Engineering Processes

Table 2: Process Improvement Topics and Subtopics

Category	Description	Topic/Subtopic References
KNOW: Process Improvement Fundamentals	Once the nature of a process is understood, one can think about process improvement. Fundamental process and quality improvement principles lay the foundation, as well as familiarity with the teachings of the quality experts. Selected process improvement standards and models are described as well as improvement approaches that can be applied at an organizational, process, or individual level.	Section 5: Process Improvement Fundamentals 5.1 Concepts and Principles 5.2 The Seeds of Process Improvement 5.3 Improvement Models and Standards 5.4 Process Appraisal 5.5 Improvement Approaches: Organizational Level 5.6 Improvement Approaches: Process Level 5.7 Improvement Approaches: Individual Level
DO: Process and Process Improvement Management	Now one starts to apply the knowledge described in the first two categories. We describe what is done in carrying out process improvement at various levels and extract example knowledge and skills used in carrying out those activities. These include analysis and synthesis of improvement methods, evaluation and judgment in making rational improvement choices, and using selected tools and techniques.	Section 6: Process and Process Improvement Management 6.1 Process Improvement Management 6.2 Process Management 6.3 Organizational Process Management

Table 2: Process Improvement Topics and Subtopics

Category	Description	Topic/Subtopic References
DO: **Culture Change**	Does culture change have anything to do with software process improvement? Do software engineers need to understand organizational culture and dynamics? We know that culture or resistance to change are frequently cited as major barriers to improvement efforts. This part of the framework describes the nature of a quality culture, culture change concepts, and approaches to changing culture.	Section 7: Culture Change 7.1 Directions 7.2 Change Concepts 7.3 Change Strategies
USE: **Tools and Techniques**	This category includes more details about tools and techniques used in process improvement activities.	Section 8: Process Improvement Tools and Techniques 8.1 Customer Value 8.2 Problem Solving 8.3 Statistical Techniques 8.4 Cost/Benefit Analysis 8.5 Risk Assessment Techniques 8.6 Defect Detection and Prevention 8.7 Benchmarking 8.8 Process Definition 8.9 Process Measurement

Table 2: Process Improvement Topics and Subtopics

Category	Description	Topic/Subtopic References
USE: **Pervasive Supporting Skills**	This last part of the framework addresses "people" skills that pervade most process improvement activities. These include key skills that form the foundation of a quality culture such as teamwork, communication, and human interaction.	Section 9: Pervasive Supporting Skills 9.1 Teamwork Skills 9.2 Communication Skills 9.3 Interaction Skills 9.4 Consulting Skills 9.5 Behavioral Change Skills

4 Process Fundamentals

"An important first step in addressing the software problems is to treat the entire software task as a process that can be controlled, measured, and improved."
—Watts Humphrey

We start off by considering fundamental process concepts: what is a process, what can one do with a process, and what are examples of software engineering processes. This section includes: General Concepts, Process Maturity Concepts, Process Development and Enactment Concepts, Process Modeling Concepts, Process Definition Concepts, Software Process Measurement, and Software Engineering Processes.

4.1 General Concepts

Process is what people do, using procedures, methods, tools, and equipment, to transform raw material (input) into a product (output) that is of value to customers. A software organization, for example, uses its resources (people, and material) to add value to its inputs (customer needs) in order to produce outputs (software products).

> **Process**. A sequence of steps performed for a given purpose [IEEE-STD-610].
>
> **Software Process**. A set of activities, methods, practices, and transformations that people use to develop and maintain software and the associated products [Paulk 93a].

Processes exist at various levels, and serve general or specific goals. At the organization level, processes interact broadly with the environment or seek organization-wide goals; at the tactical and operational levels, processes serve specific project or functional goals; at the individual level, processes accomplish specific tasks.

The process management premise is that the quality of the product (e.g. a software system) is largely governed by the quality of the process used to develop and maintain it.

> **Process context**. Organizations as systems with strategic, technical, structural, cultural, and managerial components; relation of process to other components of organizational systems; people, process, and technology as three quality leverage points; relating process and product; relating to external forces; process levels; formal and informal processes.

4.2 Process Maturity Concepts

Processes can be characterized in terms of capability, performance, and maturity.

> **Software process maturity**. The extent to which a specific process is explicitly defined, managed, measured, controlled, and effective [Paulk 93a]. The maturity of an organization's software process helps to predict a project's ability to meet its goals.

Software process capability. The range of expected results that can be achieved by following a software process [Paulk 93a]. A more mature process has improved capability (a narrower range of expected results).

Software process performance. The actual results achieved by following a software process [Paulk 93a]. A more mature process has improved performance (lower costs, lower development time, higher productivity and quality) and performance is more likely to meet targeted goals.

Maturity model. A representation of the key attributes of selected organizational entities which relate to the progress of the entities towards reaching their full growth or development [Garcia 93].

Institutionalization. Building an infrastructure and a corporate culture that supports the methods, practices, and procedures of the business so that they endure after those who originally defined them have gone; an organization institutionalizes its software process via policies, standards, and organizational structures [Paulk 93a].

4.3 Process Development and Enactment Concepts

Core concepts are emerging about software process. To meet the need for a common communication framework on software process, a small group headed by Peter Feiler and Watts Humphrey proposed a core set of terms covering the basic set of abstract process concepts. The scope of the concepts was limited to definition, modeling, and enactment issues. Feiler documents these concepts, which are fundamental knowledge for those working in software process [Feiler 92]. They are outlined below:

Framework for Process Definition. These are the basic process artifacts, which include

- **process architecture**: a conceptual framework for consistently incorporating, relating, and tailoring process elements into enactable processes
- **process design**: an embodiment of a process architecture.
- **process definition**: an enactable implementation of a process design in the form of a partially ordered set of process steps.
- **process plan**: a specification of the resources necessary for enactment of a process definition

Engineering of Processes. These concepts relate to engineering of processes, itself a process that can be engineered and defined:

- **development**: creating process architectures, process designs, or process definitions
- **tailoring**: adapting process designs and process definitions to support the enactment of a process for a particular purpose
- **planning**: developing a process plan for the enactment of a process definition

- **instantiation**: creating enactable processes from process definitions
- **evolution**: changing existing process definitions

Enactment of processes. Concepts are grouped into four areas.

- **process enactment**: the mechanics of enacting a process (agent, process constraint, enactment state, enacting process, interaction, automation)
- **process control**: monitoring, analysis, and adjustment of a process to improve its behavior(control process, monitoring, process trace, analysis, adjustment)
- **process authority**: authorization, appraisal, delegation, and intrusion
- **process assurance**: methods of adapting a process definition to address unexpected situations, and means for ensuring proper enactment of the established process definition (repair, recovery, enforcement, guidance)

Process properties. These properties relate to entire processes or elements of processes.

- **static properties**: accuracy, fidelity, fitness, precision, redundancy, scalability, maintainability
- **dynamic properties**: lifeness, robustness, fault tolerance, autonomy, responsiveness

4.4 Process Modeling Concepts

Just as a software program defines a process that a computer must follow to achieve a result, software process models define the process a software engineer follows. A software process model can be a descriptive representation of the structure of a software process or a prescriptive representation that defines how a process carries out its activities. Because of fundamental parallels between defining and modeling organizational processes and computer processes, many techniques from computer process representation can be applied to organizational process representation.

Software process modeling objectives. facilitate human understanding and communication, support process improvement, support process management, automate guidance in performing process, automate execution support.

Representation techniques. IDEF0, SADT, activity charts, module charts, state charts, Entry-Task-Validation-Exit (ETVX), flowcharts, data flow diagrams, languages, etc.

Process modeling paradigms. Programming models (process programming), functional models (HFSP), plan-based models (GRAPPLE), petri-net models (role interaction net), quantitative models.

4.5 Process Definition Concepts

Process definition consists of adding and organizing information to a process model to ensure it can be enacted. A process is defined when it has documentation detailing what is done, who does it, the materials needed to do it, and what is produced. A software process definition establishes a plan for applying tools, methods, and people to the task of software development. (See also 8.8)

Process definition activities. Product planning, process familiarization, customer identification, interviewing, analysis, model construction, verification and validation.

Components of software definition. A software definition document will consist of information about *work product, activity, and agent* viewpoints. That is, the document identifies work products to be produced, activities, and the agents involved in producing the work products.

Related terms and concepts. Process design, process management principles, life-cycle-models, descriptive modeling, prescriptive modeling, organizational process asset, perspective viewpoint, process asset, process model, process guide.

4.6 Software Process Measurement

The primary purpose of measurement is to provide insight into software processes and the products that such processes produce. (See also Section 8.9) Type and level of granularity of a measurement depend on the goals of the measurement program. The Goal-Question-Metric (G-Q-M) paradigm [Basili 84] is one framework for establishing a measurement program.

Goal. Define goals for the measurement program.

Question. Develop questions that help determine whether or not goals are being met.

Measure. Identify quantifiable answers to the questions.

Here are some examples of software-related measures.

Product measures. The SEI has proposed four core product measures [Carleton 92] upon which other metrics are built: *Size*—source statements, function points; *Effort*—person-hours (dollars); *Schedule*—elapsed time; *Quality*—problems and defects.

Process measures. Number of defects per KLOC (thousands of lines of code), function points per staff months, defects found each phase of development, percentage of defects found before functional verification test.

Quality/reliability measures. Defect quantities, defect severities, defect reports for same defect, efficiency of testing in defect removal, mean time to failure.

User satisfaction measures. User defect report, customer satisfaction indices, user requests for enhancement.

4.7 Software Engineering Processes

Software processes have been categorized and structured in different ways. Two major process breakdowns are described below.

4.7.1 Processes and Process Categories in the SPICE* Baseline Practices Guide

The SPICE Baseline Practices Guide [SPICE-BPG 94] documents the set of practices considered essential to good software engineering. The base practices are grouped into processes. Sets of processes that should be implemented to establish and improve an organization's software development, maintenance, operation, and support capabilities are organized into process categories that address the same general area of activity. Table 3 shows the five process categories and their member processes. (Section 5.3.4 describes the basic structure of the SPICE standard and its BPG.)

Table 3: Processes and Process Categories in SPICE BPG

Process Categories	Processes
Customer-Supplier Process Category: processes that directly affect the customer, support development and transition of the software to the customer, and provide for its correct operation and use	Acquire software product and/or service; establish contract; identify customer needs; perform joint audits and reviews; package, deliver, and install the software; support operation of software; provide customer service; assess customer satisfaction.
Engineering Process Category: processes that directly specify, implement, or maintain a system and software product and its user documentation	Develop system requirements and design; develop software requirements; develop software design; implement software design; integrate and test software; integrate and test system; maintain system and software.
Project Process Category: processes that establish the project, and coordinate and manage its resources to produce a product or provide services which satisfy the customer	Plan project life cycle; establish project plan; build project teams; manage requirements; manage quality; manage risks; manage resources and schedule; manage subcontractors.

* In January 1993 an international working group (WG10) was formed as part of the international standards body ISO (the International Organization for Standardization) and IEC (*the International Electrotechnical Commission) JTC1 (Joint Technical Committee 1) SC7 (Sub Committee 7) (ISO/IEC JTC1/SC7). The purpose of Working Group 10 is to create a standard for Software Process Assessment, and the mechanism used to accomplish this was to form a separate project called SPICE (Software Process Improvement and Capability Determination).

Table 3: Processes and Process Categories in SPICE BPG

Process Categories	Processes
Support Process Category: processes that enable and support the performance of the other processes on a project	Develop documentation; perform configuration management; perform quality assurance; perform problem resolution; perform peer reviews
Organization Process Category: processes that establish the business goals of the organization and develop process, product, and resource assets which will help the organization achieve its business goals	Engineer the business; define the process; improve the process; perform training; enable reuse; provide software engineering environment; provide work facilities.

4.7.2 Key Process Areas in the Capability Maturity Model for Software (CMM) *

"Each key process area identifies a cluster of related activities that, when performed collectively, achieve a set of goals considered important for enhancing process capability." —CMM for Software

The CMM [Paulk 93a] presents a set of recommended practices in eighteen key process areas (KPAs) that have been shown to enhance software development capability [Herbsleb 94]. Each KPA resides at a single maturity level. The 18 Key Process Areas have been categorized into three broad categories: management, organizational, and engineering processes [Paulk 93b]. The maturity levels, KPAs, and categorizations are shown in Table 4. Note that at Levels 4 and 5 there are KPAs that span process categories, and that no KPAs are associated with the Initial Level. (Section 5.3.1 describes the basic structure of the CMM.)

* In 1986, the Software Engineering Institute (SEI), with assistance from Mitre Corporation, began developing a process maturity framework that would help organizations improve their software process. After four years of experience with this framework, the SEI evolved the software process maturity framework into the Capability Maturity Model for Software (CMM). The initial release of the CMM was reviewed and used by the software community during 1991 and 1992 and revised based on ongoing feedback from the software community.

Table 4: The Key Process Areas by Maturity Level and Process Category

Levels	Process Categories		
	Management	**Organizational**	**Engineering**
5 Optimizing. At the Optimizing level, continuous process improvement is enabled by quantitative feedback from the process and from testing innovative ideas and technologies.	Process Change Management	Technology Change Management Process Change Management	Technology Change Management Defect Prevention
4 Managed. At the Managed level, detailed measures of the software process and product quality are collected. Both the software process and products are quantitatively understood and controlled using detailed measures.	Quantitative Process Management	Quantitative Process Management	Software Quality Management
3 Defined. At the Defined level, the software process for both management and engineering activities is documented, standardized, and integrated into an organization-wide software process. All projects use a documented and approved version of the organization's process for developing and maintaining software.	Integrated Software Management Intergroup Coordination	Organization Process Focus Organization Process Definition Training Program	Software Product Engineering Peer Reviews

Table 4: The Key Process Areas by Maturity Level and Process Category

Levels	Process Categories		
	Management	**Organizational**	**Engineering**
2 Repeatable. At the repeatable level, basic project management processes are established to track cost, schedule, and functionality. The necessary process discipline is in place to repeat earlier successes on projects with similar applications.	Requirements Management Software Project Planning Software Project Tracking & Oversight Software Subcontract Management Software Quality Assurance Software Configuration Management		
1 Initial	Ad Hoc Processes	Ad Hoc Processes	Ad Hoc Processes

5 Process Improvement Fundamentals

"Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs." —W. Edwards Deming

Quality has been a business concern for several decades, but a major innovation in software organizations has been the shift from the product to the process as the focus for quality control and improvement.

This section describes fundamentals that provide essential knowledge for pursuing process improvement. Our premise is that process improvement can only become internalized and continuous when it is based on knowledge and understanding of the principles that have caused major quality changes in other business domains. But do these principles apply to software? Yes. They have been captured in widely adopted standards and models that apply them to the software process. These standards continue to evolve as software process improvement becomes a more mature discipline and practice. Many approaches to software process improvement exist and are emerging. We include these essentials in this section.

First, major process improvement concepts and principles are presented in order to depict current thinking on the underpinnings of process and quality improvement. Then, brief introductions are made to the philosophies of the major quality leaders.

The next two sections present selected improvement models and standards, which provide guidance on improvement aspirations; and process appraisal fundamentals, which underlie methods used to characterize current practice in relation to goals.

Improvement can be carried out at several process levels and through various approaches at these levels. The last three sections describe a variety of improvement approaches at organizational, process, and individual levels.

5.1 Concepts and Principles

This section captures major concepts and principles that underlie process and quality improvement. These principles provide the foundation for carrying out process improvement activities.

5.1.1 Some Definitions

Process improvement and quality improvement are deeply entwined.

> **Process and quality improvement**. The operation of putting in place measures to strengthen weaknesses in processes which have been identified as sources of defects and risks to quality. Process and quality improvement is based on the premise that product quality is highly dependent on the processes used in its development [ImproveIT 91].

Quality improvement. Actions taken throughout the organization to increase the effectiveness and efficiency of activities and processes, and to provide added benefits to both the organization and its customers [ISO 9004-4 93].

Quality losses. Losses caused by not realizing the potential of resources in processes and activities [ISO 9004-4 93].

5.1.2 General Principles of Process Improvement

Several general principles of process improvement emerge repeatedly from the process improvement literature. Pervasive themes include:

Management. Major changes must start at the top; enabling quality improvement is a management responsibility; management must visibly endorse and support process improvement.

Involvement. Everyone must be involved; successful change requires a team effort.

Assessment/measurement. Effective change requires a goal and knowledge of the current process; understand the current process first; to use a map you must know where you are; quality improvement must be measured.

The nature of change. Change is continuous; change is normal; every defect is an improvement opportunity.

Investment. Improvement requires investment; improvement requires time, skill, and money.

Reinforcement. Sustaining change requires periodic reinforcement; rewards and incentives are necessary to establish and maintain an improvement effort.

Prevention. Crisis prevention is more important than crisis recovery.

Process. Quality improvement focuses on fixing the process, not the people; quality improvement is a continuous process.

5.1.3 Quality Concepts and Principles

The following are some examples of concepts and principles that underly specific quality standards and practices.

5.1.3.1 ISO 9000 Concepts and Principles

The ISO 9000 series of standards were developed by the International Organization for Standardization. These standards deal with quality management systems and they have been adopted as national quality standards by over 50 countries.

Principles of quality improvement [ISO 9004-4 93]

Quality of an organization's products, services and other outputs is determined by the satisfaction of the customers who use them and results from the effectiveness and efficiency of the processes that create and support them.

Quality improvement is achieved by improving processes; quality improvement is a continuous activity.

Seek opportunities for improvement, rather than waiting for a problem to reveal opportunities; opportunities to reduce quality losses guide quality improvement.

Preventive and corrective actions improve the processes of an organization.

Quality concepts for quality management systems [ISO 9004 87]

An organization should achieve and sustain the quality of the product or service produced to meet continually the purchaser's stated or implied needs.

An organization should provide confidence to its own management that the intended quality is being achieved or sustained.

An organization should provide confidence to the purchaser that the intended quality is being, or will be, achieved in the delivered product or service provided.

5.1.3.2 Total Quality Management Principles

Total Quality Management (TQM) is the application of quantitative methods and human resources to improve: the material and services supplied to an organization, all the processes within an organization, and the degree to which the needs of the customer are met both now and in the future [DOD-TQM 91], [DOD-TQM 89b].

Basic TQM principles. Continuous process improvement, process knowledge, user focus, commitment, top-down implementation, constancy of purpose, total involvement, teamwork, and investment in people.

TQM focus. Emphasize continuous improvement of processes, not compliance to standards; motivate to improve from within, rather than wait for complaints/demands from users; involve all functions, not just the quality organization; motivate and involve employees to become the driving force for improvement; satisfy the customer, not merely conform to requirements; use guides and target values as goals for improvement, not standards to which to conform; use modern process control techniques; and understand the effects of variation on processes and their implications for process improvement.

5.1.3.3 Quality Leadership Principles

Quality Leadership is a management style or practice that shifts emphasis from profits to quality [Scholtes 88].

> **Quality Leadership principles**. Customer focus, obsession with quality, recognizing the structure in work, freedom through control, unity of purpose, looking for faults in systems, teamwork, and continuous education and training.

5.1.3.4 Leadership Through Quality Principles

Leadership Through Quality (LTQ) is a process used by Xerox Corporation that is aimed at fundamentally changing the way people work and manage so that they can continuously improve the way they meet the requirements of their customers [XEROX 86].

> **Quality principles**. Quality is the basic business principle for Xerox to continue to be a leadership company; we will understand our customer's existing and latent requirements; we will provide all our external and internal customers products and services which meet their requirements; employee involvement, through participative problem solving, is essential to improve quality; and error-free work is the most cost effective way to improve quality.

5.2 The Seeds of Process Improvement

This section overviews major philosophies and principles offered by experts who brought the world's attention to quality, including W. Edwards Deming, Joseph M. Juran, Philip B. Crosby, and Masaaki Imai.

5.2.1 Management Philosophy of Deming

W. Edwards Deming is a renowned leader in the quality movement. His work [Deming 86] is seminal in this area and his ideas pervade improvement philosophy and efforts.

> *"Everyone in this field should be familiar with Deming's work." —Watts Humphrey*

> **Quality**. Quality is defined by the customer.
>
> **The Deming Chain Reaction**. Improve quality, decrease costs, improve productivity, decrease prices, increase market, stay in business, provide jobs and more jobs, return on investment.
>
> **Transformation**. The Fourteen Points; the Seven Deadly Diseases; Obstacles; and the Deming Prize.
>
> **Statistics**. Basing decisions on accurate, timely data; role of statistics to help understand, control, and improve processes; special causes of variability and eliminating them; common causes of variability and of poor quality; and quality diagnosis.

A company's extended process. Manpower, methods, materials, machines PLUS suppliers, customers, investors, and the community; the idea of a system with supportive components working together (everyone wins).

Responsibility. Management's responsibility for the process; worker's responsibilities to communicate to management; interdisciplinary teams; and the need for cooperation.

5.2.2 Management Philosophy of Juran

Quality. Quality is fitness for use.

The Juran trilogy of quality management. Quality planning (providing resources), quality control (preventing quality deficiencies from getting worse), and quality improvement (seizing opportunities to reduce chronic waste).

The costs of poor quality. Cost of inappropriate product design, cost of ineffective development/manufacturing processes, and cost of rework.

Structured annual improvements in quality. Study the symptoms of defects and failures; develop a theory on the causes of these symptoms; test the theory until the cause(s) is known; and stimulate remedial action by the appropriate departments.

A massive quality-oriented training program.

Upper management leadership. Leadership of each company's approach to product quality.

Pareto principle. Concentrate on the vital few, not the trivial many.

5.2.3 Management Philosophy of Crosby

"Quality is an achievable, measurable, profitable entity that can be installed once you have commitment and understanding, and are prepared for hard work." —Philip Crosby

Quality. Quality is conformance to requirements.

Cost of quality. Measured by the expense of nonconformance; the cost of doing things wrong.

Quality management. Systematic way of guaranteeing that organized activities happen the way they are planned.

The Quality Management Maturity Grid. Stages: Uncertainty, Awakening, Enlightenment, Wisdom, Certainty; Measurement categories: management understanding and attitude, quality organization status, problem handling, cost of quality as a percent of sales, quality improvement actions, and summation of company quality posture.

5.2.4 Quality Work in Japan

It is called *Kaizen.*

> *"Kaizen means ongoing improvement involving everyone." —Masaaki Imai*

In *Kaizen, the key to Japan's competitive success,* Masaaki Imai brings together the management philosophies, theories, and tools that have been developed and used over the years in Japan [Imai 86].

> **Concepts**. Belief in unending improvement, responsibility for maintenance and improvement, process orientation and people orientation (not result orientation); The P criteria: discipline, time management, skill development, participation and involvement, morale, and communication.
>
> ***Kaizen* by Total Quality Control** (TQC). Company-wide quality control; quality culture: building quality into people through training and leadership; training and education for *everyone*; speak with data; quality first (not profit first); the five "whys"; customer orientation; cross-functional management; and Plan-Do-Check-Act. (See also Section 5.4.7)
>
> ***Kaizen* in practice**. Management-oriented *kaizen*; group-oriented *kaizen*; individual-oriented *kaizen.*
>
> **Management concepts**. Cross-functional management; policy deployment; quality, cost, and scheduling goals; rewarding effort, not just results; and customer orientation.
>
> **Problem solving**. Problems as potential for improvement; identifying and reporting problems; top-down (design) approach; bottom-up (analytical) approach; The Seven Statistical Tools for analytical problem solving; The New Seven tools for design. (See Section 8.)

5.3 Improvement Models and Standards

Knowledge of improvement models and standards guides improvement efforts and ensures rational choice regarding the model to be followed or tailored for the organization. These models and standards document goals or change destinations.

Several improvement models and standards are available. Some describe practices to be followed; some go beyond compliance with a static standard and emphasize continuous process and quality improvement as related to business needs.

Models or standards are often part of an assessment or improvement method that may include a scheme to assess status or compliance. Guidelines for improvement may also be provided.

Four major models or standards are outlined in this section. They were selected based on their broad recognition and current usage, or (in the case of SPICE) based on expected impact and usage among the international software community. The Capability Maturity Model for Soft-

ware and SPICE are software specific; and Malcolm Baldrige National Quality Award and ISO 9001 may be used in software or other types of organizations.

Note that there are many other standards or models or awards that are widely recognized and used, and references are provided in the appendix.

5.3.1 Capability Maturity Model for Software (CMM)

The CMM applies process management and quality improvement concepts to software development and maintenance. It is a model for organizational improvement and serves as a guide for evolving toward a culture of engineering excellence. The CMM provides the underlying structure for software appraisals—assessments and evaluations. (See Section 5.4.1) It offers a staged improvement structure based on the quality principles of Deming, Juran, and Crosby [Paulk 93a], [Paulk 93b].

Critical concepts. Software process: process capability, process performance, process maturity, and institutionalization.

Structure and components of the CMM. *Maturity levels* indicate process capability and contain key process areas. *Key process areas* achieve goals and are organized by common features. *Common features* address implementation or institutionalization and contain key practices. *Key practices* describe infrastructure or activities that contribute to satisfying the goals of that key process area.

The maturity levels. Each level is a well-defined evolutionary plateau toward achieving a mature software process; each level builds a foundation for succeeding levels to use to implement process effectively and efficiently.

Level 1: Initial. Process is informal and ad hoc; performance is unpredictable.

Level 2: Repeatable. Project management system is in place; performance is repeatable; and there is a disciplined process.

Level 3: Defined. Software engineering and management processes are defined and integrated; there is a standard, consistent process.

Level 4: Managed. Product and process are quantitatively controlled; there is a predictable process.

Level 5: Optimizing. Process improvement is institutionalized; there is a continuously improving process.

The key process areas. (See Section 4.7.2.)

The common features. (See Section 6.2.2.1.)

5.3.2 Malcolm Baldrige National Quality Award

This award recognizes US companies that excel in quality management and quality achievement. The award criteria intend to help companies enhance their competitiveness through im-

proved performance. They are used as a basis for submitting an award application and are also used for self-assessment, planning, training, and other purposes [MBNQA 93]. (See also 6.1.2.)

> **Goals**. Customer satisfaction; customer satisfaction relative to competitors; customer retention; market share gain.
>
> **Core values and concepts**. Customer-driven quality, leadership, continuous improvement, employee participation and development, fast response, design quality and prevention, long-range outlook, management by fact, partnership development, corporate responsibility and citizenship.
>
> **Measures of progress**. Product and service quality; productivity improvement; waste reduction/elimination, supplier quality.
>
> **Award criteria framework**. Leadership; information and analysis (the basis for analysis of results, process improvement, and maintaining alignment of processes with business strategy); strategic quality planning (integrating quality and operational performance requirements with business strategy); human resource development and management; management of process quality; quality and operational results; customer focus and satisfaction.

5.3.3 ISO 9001

The ISO 9000 series of standards deal with quality management systems that can be used for external quality assurance purposes. ISO 9001 *Quality systems - Model for quality assurance in design/development, production, installation, and servicing* is the standard pertinent to software development and maintenance. This standard specifies quality system requirements for use where a contract between two parties requires the demonstration of a supplier's capability to design and supply a product [ISO9001 87].

> **ISO 9001 Quality System Requirements**. Management responsibility; quality system; contract review; design control; document control; purchasing; purchaser-supplied product; product identification and traceability; process control; inspection and testing; inspection, measuring, and test equipment; inspection and test status; control of nonconforming product; corrective action; handling, storage, packaging, and delivery; quality records; internal quality audits; training; servicing; and statistical techniques.
>
> **Certification**. ISO 9001 certification provides evidence that a supplier has reached a minimum level for its quality management system. (See also Section 6.1.2.)

ISO 9000-3 provides guidelines for the application of ISO 9001 to the development, supply, and maintenance of software. The guidelines are intended to describe suggested controls and methods for producing software that meets a purchaser's requirements. ISO 9000-3 structures the ISO 9001 quality system requirements into three quality system areas (below) and renames and elaborates selected clauses [ISO9000-3 91].

> **Quality system - Framework**. Management responsibility; quality system; Internal quality system audits; corrective action.

Quality system - Life-cycle activities. Contract review; purchaser's requirements specification; development planning; quality planning; design and implementation; testing and validation; acceptance; replication, delivery and installation; maintenance.

Quality system - Supporting activities. Configuration management; document control; quality records; measurement; rules, practices and conventions; tools and techniques; purchasing; included software product; training.

5.3.4 Software Process Improvement and Capability Determination (SPICE) Process Framework

SPICE is a proposed international standard that provides an assessment method whose results can be used for process improvement or for process capability determination. The assessment method (See Section 5.4.2.) rates processes against the process framework defined in the Baseline Practices Guide (BPG). That framework provides a roadmap for improvement.

The BPG defines practices and processes which should be implemented to establish and improve an organization's software capabilities. Practices are organized using an architecture which provides two different categorizations of the practices [SPICE-BPG 94].

SPICE Architecture: Grouping by type of activity. A *process category* addresses the same general area of activity and contains processes; a *process* achieves a purpose and contains activities; a *base practice* is an activity that addresses the purpose of a particular process. (See Section 4.7.1 for a description of the process categories.)

SPICE Architecture: Grouping by type of implementation or institutionalization activity. A *capability level* contains common features that work together to provide a major enhancement in the capability to perform a process; a *common feature* contains practices that address the same aspect of process implementation or institutionalization; a *generic practice* is an implementation or institutionalization practice that enhances the capability to perform any process. (See Section 6.2.2.2 for a description of the common features.)

A process contains both base practices and generic practices and may be assessed in terms of capability levels, common features, or generic practices.

The Capability Levels. Provide an improvement roadmap for an organization to improve any specific process.

Level 0: Not-Performed. General failure to perform the base practices of the process.

Level 1: Performed-informally. Base practices of the process are generally performed.

Level 2: Planned-and-Tracked. Performance of the base practices of the process is planned and tracked.

Level 3: Well-Defined. Base practices are performed according to a well-defined process using approved, tailored versions of the standard documented process.

Level 4: Quantitatively-Controlled. Detailed measures of performance are collected and analyzed.

Level 5: Continuously-Improving. Quantitative process effectiveness and efficiency goals (targets) for performance are established based on business goals of the organization; continuous process improvement against these goals is enabled.

5.4 Process Appraisal

Process appraisals are carried out to characterize current practices in an organization. They rate an organization's process maturity against a reference model.

There are many possible types of appraisals with different goals, uses, methods, and supporting tools. Appraisals may provide information to help customers select software suppliers, to guide suppliers with internal process improvement efforts, or to guide joint customer/supplier process improvement and/or risk management efforts [Masters 95].

Assessments for the purposes of award application (such as applying for the Malcolm Baldrige National Quality Award) or for certification (such as seeking ISO9000 certification) may also be used to characterize current practice in relation to those standards. These may be part of an organization's process improvement strategy. (See Section 6.1.2.)

Here we present appraisal methods pertaining more specifically to software process appraisal.

5.4.1 CMM-Based Appraisals

Several appraisal methods are based on the CMM for software as a reference model.

5.4.1.1 CMM Appraisal Framework (CAF)

The CMM appraisal framework (CAF) provides a framework for rating the process maturity of an organization against the CMM for software. It includes a generic appraisal architecture and it defines requirements for developing CAF compliant appraisal methods. The primary activities of a CAF compliant appraisal method are the following [Masters 95]:

Plan and prepare for appraisal. Analyze requirements, select and prepare team, select and prepare participants, develop appraisal plan.

Conduct appraisal. Collect and record data, consolidate data, make rating judgements

Report results. Report appraisal results, protect confidentiality, preserve records.

5.4.1.2 CMM-Based Appraisal for Internal Process Improvement (CBA IPI)

CBA IPI is an SEI method for conducting software assessments. It contains rules for collecting information, assessing reliability of the information, making judgements about the current state of the process, and reporting the results. The method identifies an organization's strengths and weaknesses to help build an improvement program action plan [CBA IPI 95].

5.4.1.3 Software Capability Evaluation (SCE)

A CMM-based software capability evaluation (SCE) is an independent evaluation of an organization's software process as related to a particular acquisition. An acquirer uses an SCE to help determine a supplier's ability to produce a particular product [SCE:SPA 92], [CBA Project 94].

5.4.1.4 Software Process Assessment (SPA)

A CMM-based software process assessment (SPA) is an in-house determination primarily of weaknesses of the software process in an organization as a whole. An organization can choose an SPA as part of an overall process improvement program [SCE:SPA 92], [Olsen 89].

5.4.1.5 Interim Profile

An interim profile is a CMM-based method to rapidly measure an organization's software engineering process maturity between software process assessments. Activities of the method include: logistics and setup, initial data collection and analysis, review and revision of draft project profiles, distribution of final profiles, and audit of the interim profile process [Whitney 94].

5.4.2 SPICE Process Assessment

In the SPICE standard, process assessment is used to understand an organizational unit's current processes. The reference model used is the SPICE Baseline Practices Guide.

Assessment is initiated by a sponsor's desire for process improvement or by an acquirer's wish to evaluate the capability of a supplier. In each case the initiator determines the assessment purpose, scope, constraints, responsibilities, and extended process definitions [SPICE-PAG 94].

> **Assessment approaches**. Self-assessment (for internal improvement), team-based, tool-based; independent assessment.
>
> **Assessment stages**. Review assessment input, select process instances, prepare for assessment, collect and verify information, determine actual ratings, determine derived ratings, validate ratings, present output.
>
> **Success factors**. Commitment, motivation, confidentiality, relevance, credibility.
>
> **Assessment instrument**. A probe to capture, collate, and formalize process information.

5.5 Improvement Approaches: Organizational Level

A maturity model or a quality standard can provide goals for improvement, but how do you go about improving?

This section describes a variety of improvement approaches that delineate various phases, stages, or activities required for process improvement at the organizational level. Knowledge of various approaches enables organizations to be familiar with steps, to compare and contrast approaches, analyze parts, synthesize or tailor an approach to meet circumstance, or derive a new approach.

These approaches vary in scope. Some encompass organizational transformation issues such as management structures, culture change, and environmental factors; others focus on a narrower view of process improvement.

All of the approaches are top-down approaches emphasizing senior management sponsorship and organization-wide planning. All of the approaches lead to selection and improvement of specific processes. (Approaches for improvement at the process level are discussed in the next section.)

Most approaches are generic and can be used to pursue any improvement goals. Note that the approaches described here are *examples* of process improvement strategies that are in use or proposed as standards. Many other approaches exist; several are referenced in the Appendix.

To distinguish between activity levels, sometimes organizational improvement efforts are called process improvement *programs*, while spin-off activities at the process level may be called process improvement *projects*.

5.5.1 The Shewhart (Deming) Cycle

This classical management strategy provides a systematic approach to controlling and improving quality by studying a process and analyzing its performance through four steps: plan, do, check, and act. Deming further developed this approach in his process improvement work.This strategy can be applied at various process levels and several improvement approaches are derived from this basic cycle [Shewhart 31], [Deming 86].

Plan. Define the problem; state improvement objectives.

Do. Identify possible causes of the problem; establish baselines; test change.

Check. Evaluate; collect data.

Act. Determine effectiveness; implement system change.

5.5.2 An Integrated Approach to Software Process Improvement (The IDEAL℠* Approach)

This SEI software process improvement approach describes phases and activities entailed in software process improvement. The five phases are Initiate, Diagnose, Establish, Act, Leverage (hence, IDEAL) [Radice 94].

> **Initiating phase**. Stimulus for improvement; set context and establish sponsorship; establish improvement infrastructure.
>
> **Diagnosing phase**. Appraise and characterize current practice; develop recommendations and document phase results.
>
> **Establishing phase**. Set strategy and priorities; establish process action teams; plan actions.
>
> **Acting phase**. Define processes and measures; plan and execute pilots; plan, execute, and track installation.
>
> **Leveraging phase**. Document and analyze lessons; revise organizational approach.

5.5.3 Software Process Improvement (SPI) Roadmap

The software process improvement (SPI) roadmap is a long-range, integrated plan for initiating and managing a SPI program. It provides a phased, generic approach addressing both strategic and tactical activity levels. This approach was developed as the result of a strategic collaboration between the SEI and Hewlett Packard Company. It is based on the work of several SEI projects, and the concepts were proven with SEI clients and internal Hewlett Packard clients [McFeeley 94].

> **SPI roadmap phases**. Initiating SPI; baselining (understanding the current processes and opportunities); implementing (developing and sustaining improvements).
>
> **Strategic level activities**. Initiate SPI; manage the SPI program; build SPI strategy.
>
> **Tactical level activities**. Baseline current state; develop improvements; deploy improvements.
>
> **SPI infrastructure**. Management Steering Group (MSG); Software Engineering Process Group (SEPG); process action teams (PATs).

5.5.4 The Software Engineering Improvement Method

The software engineering improvement method is a systematic method of integrated software engineering improvement that the SEI is employing with pilot customers. The objective is to provide a systematic means for achieving software engineering improvement over time. The premise is that for a given organization, desired software engineering practices, technologies,

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*. IDEAL is a service mark of Carnegie Mellon University.

and organizational capabilities can be defined as goal states to be achieved along with the processes, methods, and organizational infrastructure necessary to achieve them. Once goal states are defined, the way to attain them can be described as a software process definition, and managed as a well-defined software engineering project [SEIM 94].

Define software engineering improvement framework. Describe vision, define software engineering goals linked to organizational goals and tailored to software engineering capabilities; identify anticipated technology and process needs; identify appropriate methods to achieve specified goals.

Form software engineering improvement process definition. Build on the defined improvement framework; decide on sequence of methods to attain goals; define conditions for starting improvement activities and criteria for completeness; identify types of agents who will play a role in the improvements.

Form software engineering improvement project plan. Attach schedules, resources, people to the software engineering improvement process definition.

Manage the improvement project plan. Create guidelines; ensure adoption of specified organizational changes, technologies, and processes on a just-in-time basis; monitor and verify results; communicate status, results, and lessons learned; adjust priorities for ongoing or next improvement activities.

5.5.5 SEI Leadership Series Strategy for Process Improvement

The SEI Leadership Series of courses offers a strategy for process improvement including the following 10 points [SEI LSC].

Where are you now. Process definition baseline; metrics baseline; process assessment baseline.

Where are you going. Goal Setting.

How do you get there. Quality improvement; productivity improvement; risk management improvement.

Make it happen. Training and people development; process organization; implementation plan.

5.5.6 Advanced Quality System (AQS)

Boeing's Advanced Quality System (AQS) for software provides a documented approach to meeting progressively higher process and product quality standards [Boeing 94]. This approach is tied to measuring improvement in accordance with the CMM for software, although it may also be used in connection with other models which have equivalent goals. AQS is used to ensure suppliers are committed to the continuous improvement of software processes and products. There are four stages that are tied to the maturity level of the supplier.

Stage I (for organizations at CMM maturity Level 1 or 2). Prepare process improvement commitment, conduct assessment, prepare process improvement plan.

Stage II (for organizations at CMM maturity Level 1 or 2). Implement process improvement plan.

Stage III (for organizations at CMM Level 3). Prepare product quality measurement plan, implement product quality measurement plan.

Stage IV (for organizations at CMM Level 4 or 5). Prepare product quality targets plan, implement product quality targets plan, re-evaluate and maintain targets.

5.5.7 Managing Process Improvement

Software Productivity Consortium's Managing Process Improvement [SPC 94] is a comprehensive approach for initiating and sustaining a process improvement program. The approach addresses five organizational subsystems (strategic, technological, human/cultural, structural, and managerial) with special focus on improving the managerial and technological areas. Five steps are carried out iteratively to progress towards improvement objectives.

Understand context. Build/reinforce sponsorship and foundation, define/update improvement strategies, assess/understand process, review context.

Analyze risks and select strategy. Analyze and resolve risks, select improvement strategy, commit to strategy.

Plan improvement. Define/update action plan, commit to action plan.

Implement improvements. Implement, manage and monitor, review process improvements.

Review and update. Review progress, define/update program plan, commit to proceed.

5.5.8 SPICE Process Improvement Guide

The SPICE Process Improvement Guide provides a complete framework for software process improvement including a methodology for software process improvement and guidance on the following topics: using SPICE assessment results, how to measure software process effectiveness and improvement effectiveness, how to use business goals to drive identification of improvement actions, how to use the SPICE Baseline Practices Guide as a roadmap for improvement, and how to consider people issues and how to deal with management issues for software process improvement [SPICE-PIG 94].

The software process improvement methodology. Examine organization's need; initiate process improvement; prepare and conduct SPICE process assessment; analyze assessment results and derive action plan; implement improvements; confirm/validate improvements; sustain improvement goals; monitor performance/continue process improvement.

5.5.9 ISO 9004-4 Guidelines

ISO 9004-4 *Quality management and quality system elements - Part 4: Guidelines for quality improvement* provides the following guidelines for implementing continuous quality improvement within an organization [ISO9004-4 93].

> **Managing for quality improvement**. Organizing for quality improvement; planning for quality improvement, measuring quality improvement, reviewing quality-improvement activities.
>
> **Methodology for quality improvement**. Involving the whole organization; initiating quality improvement projects or activities; investigating possible causes; establishing cause-and-effect relationships; taking preventive or corrective actions; confirming the improvement; sustaining the gains; continuing the improvement.

5.6 Improvement Approaches: Process Level

Improvement at the process level addresses positive change in the way the work is accomplished. It includes refining workflows, eliminating effort that does not add value, reducing variation, and controlling and improving the process.

The improvement of a specific process may be initiated in the context of an organizational improvement effort that has targeted that process for improvement. Alternately, a project or team may independently decide to improve its processes. This may lead to broader process improvement in a middle-out way.

There are several improvement models at this level, and three of them are described below. Others are referenced in the Appendix.

5.6.1 Model of Progress: Joiner Associates

This approach shows the general progression of events in process improvement teams and includes a model of progress and a plan for process improvement.

> **Model of progress**. Clarify goals; educate and build the team; investigate the process; analyze data and seek solutions; take appropriate action; closure.
>
> **Plan for process improvement**. Understand the process; eliminate errors; remove slack; reduce variation; plan for continuous improvement [Scholtes 88].

5.6.2 Logistics Management Institute—Continuous Improvement Process: Process-Improvement Model

This model incorporates the Plan-Do-Check-Act approach and also addresses the need to standardize processes [Mansir 89].

> **Set the stage for process improvement**. Select the team, train team

Select a process to improve. Identify opportunities, prioritize, choose, identify major problems and root causes, identify measurement points.

Define the process. Customers, suppliers, how process currently performed, measures.

Standardize the process. Institutionalize current best way to perform that process: Standardize-Do-Check-Act; train; assess and eliminate causes of deviation from standard.

Tighten up the process. Ensure process meets requirements, establish data collection system.

Improve the process. Plan-Do-Check-Act.

Assess improvement performance. Document improved performance

5.6.3 Quality Improvement Process / Problem-Solving Process: Xerox

The Leadership Through Quality (LTQ) approach to process improvement includes two processes for improvement. The Quality Improvement Process (QIP) is a model for changing work processes to improve quality; the Problem Solving Process (PSP) is part of the QIP, and is used to find solutions to problems that arise during the QIP [PSP 91], [QIP 91].

Quality Improvement Process

Planning for quality. Identify output; identify customer; identify customer requirements; translate requirements into supplier specifications.

Organizing for quality. Identify steps in work process; select measurements; determine process capability.

Monitoring for quality. Evaluate results; recycle.

Problem Solving Process

Identify and select problem; analyze problem; generate potential solutions; select and plan the solution; implement the solution; evaluate the solution.

5.7 Improvement Approaches: Individual Level

Individual improvement approaches are techniques for self improvement. They may be applied within the context of a broader improvement effort, or simply at an individual level. They may be used to initiate broader process improvement in a bottom-up way. These approaches offer ways for anyone to apply discipline to everyday activities.

Two examples are described below. (See also 7.3.5 and 9.3.)

5.7.1 Personal Software Process (PSP)

The personal software process (PSP) is a paradigm suggested by Watts Humphrey. Its purpose is to improve individual software engineers productivity, and its approach is based on a

disciplined application of software development process to individual and small teams. PSP helps individual software engineers improve their skills, better manage and control their work, establish personal goals for their processes, define the methods they will use, measure their work, and analyze the results [Humphrey 94a].

PSP paradigm. Each practitioner establishes personal process goals, defines the methods to be used, measures the work done, analyzes the result obtained, and based on the analysis adjusts the method.

PSP stages. PSP takes the practitioners through a set of evolutionary stages called the Baseline Process (PSP0), the Personal Planner Process (PSP1), Personal Error Management (PSP2), Personal Design Principles (PSP3), the Cycle Personal Process (PSP4), and the Team Software Process (TSP).

5.7.2 Logistics Management Institute—Continuous Improvement Process: Personal-Improvement Model

This applies the LMI CIP Transformation Model to individual improvement efforts. It involves establishing a vision for individual improvement, enabling that effort, focusing on continuous improvement, and improving through self-evaluation [Mansir 89].

Envision personal improvement. Self-awareness; relationships with your customers and suppliers.

Enable personal improvement. Self education, learn process improvement concepts, principles, tools.

Focus on improvement. Establish goals, align activities with goals, create time for improvement activities, commitment.

Improve your job. Define your processes, remove complexity.

Improve yourself. Commitment to personal improvement, communicate, remove barriers.

Help others improve. Train and coach others, encourage others.

Evaluate your improvement progress. Measure and document your performance; reward yourself.

6 Process and Process Improvement Management

"The objectives of software process management are to produce products according to plan while simultaneously improving the organization's capability to produce better products." —Watts Humphrey

Section 4 described general *process* concepts and presented examples of specific software engineering processes that can be improved. Then Section 5 presented *process improvement* concepts, models, standards, and approaches to improving those processes. These are what one must *know* as one embarks on process improvement.

We now describe what one might *do* in the application of those concepts. We extract major activities carried out during process improvement and give examples of knowledge and skills used in those activities. Process improvement skills are further described in later sections.

Should improvements be made in a top-down, middle-out, or bottom-up way? It depends on many things such as context, circumstance, and culture. Improvement may be carried out in a parallel way at all levels; the efforts are highly interrelated. As far as *initiating* process improvement, we offer the following view:

"In one sense, it does not matter where an organization begins to focus on improvement; the important decision is making the commitment to improve." —Betty Deimel [Deimel 94b]

In this section we describe process improvement at two levels: organizational-level process improvement activities, which we call process improvement management, and activities to manage and improve a single process, which we call process management. We devote the last section to some topics in organizational process management.

6.1 Process Improvement Management

In this section we describe the major activities in carrying out a top-down improvement effort at the organizational level. These are presented in a generic framework of activity areas based on the commonalities among the approaches in Section 5.5.

6.1.1 Initiating Process Improvement

Process improvement occurs within the context of an organization's strategic plans and business objectives.

6.1.1.1 Recognizing Need for Improvement

Process improvement requires some stimulus to initiate the improvement effort; these stimuli derive from business needs. It is important to identify risk factors such as the risk of not undertaking improvement or the risk of failure in improvement undertaking.

Internal drivers. Desire to increase competitiveness: cost reduction, achievement of customer quality goals, reduction of time to market, predictability; desire to attain corporate vision, adopt new values; gaps between current and desired capability.

External requirements. Contract requirements, product requirements, certification requirements, industry benchmark requirements, customer feedback, market decline, gaps between current performance and customer/market expectations; offshore competition; policy changes.

Knowledge and skills: market research, environmental awareness, risk assessment, benchmarking, customer value determination.

6.1.1.2 Visioning and Goal Setting

Improvement is driven by a vision of what is trying to be created by the improvement effort.

Visioning. Deriving and communicating a vision; search conferences to derive a shared vision; determining the corporate mission.

Evaluation and selection. Evaluating improvement models and standards vs. business needs; selecting or tailoring the improvement model/standard.

Goal setting. Setting improvement goals on quality, productivity, risk management, maturity level; setting goals that are quantitative, reasonably aggressive, achievable, measurable, and visible; relating rewards to goals.

Critical success factors. Identifying those actions that will enable an enterprise to achieve its goals.

Communicating goals. Communicating authentically, so that goals are seen as achievable, to everyone, and so that the goals are related to the personal objectives of others.

Knowledge and skills. Understanding improvement models and standards, understanding business needs, cost/benefit analysis, feasibility studies, quality measurement, deriving process goals from business needs or strategies, costs of low quality, how to document and substantiate return on investment, visioning and goal setting; knowledge of the business/customers, communication.

6.1.1.3 Planning for Process Improvement

Strategic plans document the strategy to guide the organization and the process improvement program for the next three to five years.

Evaluation and selection. Evaluating improvement approaches vs. goals and organizational constraints/situation; selecting or tailoring the approach.

Strategic planning. Deriving the strategic plan to meet business needs; linking software process improvement to the organization's strategic direction and objectives; process improvement planning and estimation; resources, activities, schedule, milestones, review points, risks, reporting; software process improvement as a strategic initiative; tying vision and goals to strategic plan.

Communicating the plan.

Knowledge and skills: software process improvement planning and estimating, understanding improvement objectives and approaches, communication.

6.1.1.4 Organizing for Process Improvement

There must be a basic organizational infrastructure in place.

Basic improvement infrastructure. Management steering committee, process group (Software Engineering Process Group), working groups (process action teams); roles, responsibilities, charters; relationships; reporting structures.

Establishing commitment. Building executive support, sponsorship, building the infrastructure, estimating and assigning resources and responsibilities, funding and empowering.

Roles in process improvement. Agents, appraisal team, champions, line managers, participants, pilot project personnel, process action teams, software practitioners, sponsors, support organizations.

Knowledge and skills: consulting skills, contracting, negotiating, teamwork skills, organizational development skills.

6.1.2 Establishing Baselines

"If you don't know where you are, a map won't help." —Watts Humphrey

Baselines describe the way an organization currently performs its business and detail the starting point for measuring improvement. Baselines provides a systematic and thorough way to understand and document current status.

The organization must determine what to baseline and how often to do it. For internal process improvement, process appraisals may be complemented with measurement or risk assessment. Contract requirements, certification, award aspirations, or customer evaluation needs may determine the baselining methods.

6.1.2.1 Process Appraisal

Process appraisals are used to gather data about process issues, to build consensus among staff and management concerning issues and priorities, and to motivate improvement. There are a variety of appraisal methods used in the context of different reference models, and they are used for various purposes as described in Section 5.4. Most are based on questionnaires

and interviews, but automated tools may be available. Assessments result in a report describing strengths, weaknesses, and recommendations for addressing weak areas.

Assessment principles are similar: secure sponsorship, start with a process framework, observe strict confidentiality, involve senior management, approach assessment collaboratively, and focus on action.

Appraisal methods. CMM-based appraisal methods; SPICE conformant assessment, risk assessment.

Complementary techniques. Special meetings, search conferences, focus groups, surveys, interviews, routine postmortems, lessons learned activities.

Evaluation and selection. Choosing an appraisal method; criteria and considerations; tailoring or developing an appraisal method; constructing assessment instruments; common rating frameworks.

Preparing for assessment. Identifying sponsor; selecting assessors (third-party, in-house, assisted assessment); determining purpose, scope, constraints, responsibilities; selecting projects/areas/processes for assessment.

Conducting the appraisal. Data gathering, rating, scoring, profiling, validating, reporting on findings.

Assessors. Skills and training.

Knowledge and skills: appraisal methods, assessment procedures, data gathering, analysis, sampling, teamwork, reporting, communication, risk assessment.

6.1.2.2 Measurement Baselining

A measurement baseline identifies the current measurement data that is available and sets up basic measurement methods to be used.

Measurement goals. Define goals, outline measures, define measures, define data collection, analysis, and validation procedures, establish initial measurement baseline (initial level of business and process metrics against which to measure progress).

Metrics baseline. Some example basic metrics: lines of code, function points, person-months, dollars, elapsed time, defects, customer satisfaction indices; predictability (risk); historical and ongoing data.

Knowledge and skills: measurement, data collection and analysis.

6.1.2.3 Developing an Organizational Risk Profile

An organizational risk profile will help determine organizational risks to software process improvement.

Risk management improvement. Establish a risk management action plan: identify, analyze, plan, track, control, and communicate.

Climate assessment. Identify barriers and leverage points across the organization that will affect the process improvement program.

Knowledge and skills: risk assessment, risk management, change management.

6.1.2.4 ISO Certification

If an organization is seeking ISO 9000 certification, baselining takes a different form [Spizizen 92].

Assessment approaches. Selecting the quality assessment approach (self-assessment, second-party customer audit, third party registration); selecting the registrar; periodic surveillance; re-audits.

Audit process. Appraisal of quality manual, assessment to evaluate conformance to documented procedures, presentation of findings with any recommendations for corrective action.

6.1.2.5 Malcolm Baldrige National Quality Award Assessment

Applying for an award such as the Malcolm Baldrige National Quality award is another approach to baselining [MBNQA 93].

Assessment system. Criteria are a set of 28 basic, interrelated, results-oriented requirements (examination items); scoring guidelines that define assessment dimensions (approach, deployment, and results); and key factors used in assessment relative to each dimension.

Award examination. Applicant prepares application package including information and data on improvement processes and results; uses of the award criteria for self-assessment.

Application review. Independent review and evaluation by Board of Examiners, consensus review and evaluation, site visits, judges' review and recommendations, feedback to applicants.

6.1.3 Setting Priorities

After baselines have been established, assessment results must be analyzed to derive priorities and action plans. Priorities will depend on business objectives and the improvement standard or model selected.

For example, an organization may follow the CMM approach towards establishing organizational capability and proceed according to the ordering of processes at the maturity levels. Organizational process improvement may also be achieved by setting priorities for improving the processes in the Organization Process category of the SPICE BPG.

The processes to improve may be organizational or project level processes, supporting processes, product engineering processes, or any processes deemed central to business needs.

Prioritization. Identify and prioritize improvement areas.

Goal setting. Identify improvement goals and set targets (define quantitative goals for each priority area; devise suitable metrics to measure achievement of these goals; set appropriate target values for these metrics, considering risks; ensure consistency with business strategies and goals).

Action planning. Derive action (tactical) plan including: mission, critical success factors, improvement actions, process goals and improvement targets (measures), responsibilities for actions, initial estimates of cost and schedule, deliverables, communication, and verification methods, risks to products and the organization if actions are not taken.

Initiate improvement projects. Initiate projects to implement action plans; establish the process action teams or working groups who will work to improve the priority processes.

Knowledge and skills: action planning, goal setting, measurement, team building, risk assessment, understanding of process improvement standards and models, decision making.

6.1.4 Improving the Process

To improve the processes that have been identified, one must follow a process level improvement approach. (See Section 5.6 and also Section 6.2.) Process level improvement activities are carried out by teams [Scholtes 88].

Understand the process. Describe/define the process, identify customer needs and concerns, develop a standard process.

Eliminate errors. Identify mistakes, detect defects, identify less error-prone procedures, restructure the work environment.

Remove slack/streamline the process. Examine the value of each step, make steps more efficient, eliminate steps, eliminate rework, build simpler products, write fewer lines of code, reduce change-over and cycle times, monitor improvements.

Reduce variation. Reduce variation in measurement systems, bring the measurement process under statistical control, reduce variation in the process, eliminate special causes of variation, bring the process under statistical control.

Plan for continuous improvement.

PLAN for monitoring of changes or plan a change or a test aimed at improvement.

DO the monitoring or the change (preferably on a small scale); plan and execute pilots.

CHECK the results or study what happened, what did we learn?

ACT to make continuous improvements (adopt the change or abandon it and go through the cycle again).

Knowledge and skills: problem solving, process definition, measurement, statistical control, defect detection, data gathering, data reduction, analysis, reporting.

6.1.5 Deploying the Improvement

Processes that have been improved in a controlled environment are now deployed across the organization.

Confirm improvements. Confirm that planned goals and targets have been reached; re-evaluate risks associated with the improved process; evaluate costs and benefits.

Create installation and rollout plan. Consider training, communication, timing, reinforcement; consider rollout alternatives: piloting in small areas, deploy across the organization, or variations in between; consider costs, timing, and risks; consider environmental changes: human and cultural factors.

Sustain improvement gains. Monitor institutionalization; offer encouragement, ensure improved processes work as expected.

Knowledge and skills: risk assessment, cost/benefit analysis, training, communication, organizational issues, transition strategies, culture change.

6.1.6 Leveraging

The improvement cycle repeats to incorporate lessons learned and continuously improve the process improvement process.

Lessons Learned. Document and analyze data collected, incorporate lessons learned, defect prevention for next cycle.

Monitor performance. Review the continuing process improvement effort to ensure: the program and projects remain appropriate to organization's needs, further projects are initiated as appropriate, the process improvement process itself is improved, continuous improvement becomes and remains a feature of the organization's values, attitudes, and behavior.

Knowledge and skills: data analysis, defect prevention, cost/benefit analysis.

6.2 Process Management

This section describes generic process management practices used to manage any process. First process management essentials are extracted from various process level improvement approaches, such as those described in Section 5.6. Then we describe generic process man-

agement practices from the CMM and SPICE. Lastly, risk management practices are introduced as part of process management.

The activities described here may be carried out as spin-off projects from an organizational process improvement program, or they may be carried out by a project team seeking to improve its own processes following a middle-out improvement strategy.

6.2.1 Basic Process Management Activities

Process definition. Deriving a standardized framework for task implementation, evaluation, and improvement; documenting standards and procedures; an undefined process can not be controlled; an uncontrolled process can not be improved consistently.

Process execution. Defining the methods and techniques used to produce quality products.

Analysis. Making and using measurements of software products and processes; establishing baseline process performance.

Process control. Establishing mechanisms to ensure performance of defined processes; identifying and correcting *special causes* of poor quality; keeping process performing as intended within control limits on key quality parameters.

Process improvement. Identifying and rectifying *common causes* of poor quality by making basic changes to the underlying process.

Knowledge and skills: statistical process control, measurement, process definition, teamwork, problem solving, defect detection and prevention, interaction skills.

6.2.2 Common Features

Common features of process management pertain to generic practices or activities that apply to any process. Two sets of common features are provided: those attributes that offer guidance on ways to ensure that a process is effectively managed (CMM), and those practices that guide process managers through process capability levels and lead to the continuous improvement of a process (SPICE).

6.2.2.1 Common Features of the Capability Maturity Model for Software (CMM)

"The common features are attributes that indicate whether the implementation and institutionalization of a key process area is effective, repeatable, and lasting." —CMM

There are five common features in the CMM, and the key process areas at all levels are organized by common features [Paulk 93a].

Commitment to perform. Actions the organization must take to ensure that the process is established and will endure, such as establishing organizational policies and senior management sponsorship.

Ability to perform. Preconditions that must exist in the project or organization to implement the software process competently, such as securing resources and funding, organizational structures, and training.

Activities performed. Roles and procedures necessary to implement a key process area, such as establishing plans and procedures, performing the work, tracking it, and taking corrective actions as necessary.

Measurement and analysis. The need to measure the process and analyze the measurements to determine the status and effectiveness of the activities performed.

Verifying implementation. Steps to ensure that the activities are performed in compliance with the process that has been established, such as reviews and audits by management and software quality assurance.

6.2.2.2 Common Features of the Software Process Improvement and Capability Determination Standard (SPICE)

"A common feature is a set of practices that address the same aspect of process implementation or institutionalization." —SPICE

There are eleven Common Features (CFs) in the SPICE standard and they are ordered by capability level. Each is elaborated with generic practices intended to enhance the capability to perform any process. The generic practices are listed below in parentheses after each common feature [SPICE-BPG 94].

Performed-Informally level CFs. Base practices are performed (perform the process).

Planned-and-Tracked level CFs. Planning performance (allocate resources, assign responsibilities, document the process, provide tools, ensure training, plan the process); disciplined performance (use plans, standards, and procedures; do configuration management); verifying performance (verify process compliance, audit work products); tracking performance (track with measurement, take corrective action).

Well-Defined level CFs. Defining a standard process (standardize the process, tailor the standard process); performing the defined process (use a well-defined process, perform peer reviews, use well-defined data).

Quantitatively-Controlled level CFs. Establishing measurable quality goals (establish quality goals); objectively managing performance (determine process capability, use process capability).

Continuously-Improving level CFs. Improving organizational capability (establish process effectiveness goals, continuously improve the standard process); improving process effectiveness (perform causal analysis, eliminate defect causes, continuously improve the defined process).

6.2.3 Risk Management

Risk management underlies process management at all levels. It entails knowing how to determine and analyze risks, knowing which risks are most important to look for and why, and knowing how to mitigate and monitor risks. Several risk management strategies are available [Carr 93], [Boehm 89], [Boehm 91], [Charette 90].

The SEI risk management paradigm is composed of different software development risk management activities. The objective of this paradigm is to provide a disciplined and systematic method of managing software development risk in order to control the quality, cost, and schedule of software products [Carr 93].

> **Identify**. Surfacing risks; raising concerns and issues; data collection.
>
> **Analyze**. Converting risk data into risk decision-making information; determining the "right" risks to work on.
>
> **Plan**. Turning risk information into decisions and actions through planning; developing actions, prioritizing risk actions, creating an integrated risk management plan.
>
> **Track**. Monitoring the status of risks and actions taken to ameliorate risks; identifying and monitoring risk metrics to evaluate status of risks and risk mitigation plans.
>
> **Control**. Correcting for deviations from planned risk actions.
>
> **Communicate**. Pervasive and critical to this paradigm; communication about risks must take place across developers, customers, users; to and between organizational levels and entities.

6.3 Organizational Process Management

Here we provide more information about organizational processes of the CMM for software and the SPICE Baseline Practices Guide. Both of these models include processes for organizational process improvement and management.

6.3.1 Key Process Management Processes of the CMM

The key process areas (KPAs) at levels 3, 4, and 5 of the CMM address the process improvement process once basic project management processes are in place. These KPAs, along with their goals and examples of related knowledge and skills, are described below [Paulk 93a]. (Note that the software product engineering KPA is not included since these knowledge and skill areas are described in other sources such as in Ford [Ford 91].)

Level 3 KPAs focus on addressing management processes across all projects.

> **Organization process focus**. Establish the organizational responsibility for software process activities that improve the organization's overall software process capability.

Knowledge and skills: process control techniques; organizational change management; planning, managing, and monitoring the software process; technology transition.

Organization process definition. Develop and maintain a usable set of software process assets that improve process performance across the projects and provide a basis for cumulative, long-term benefits to the organization.

Knowledge and skills: process analysis and documentation methods; process modeling.

Training program. Develop the skills and knowledge of individuals so they can perform their roles effectively and efficiently.

Knowledge and skills: training in instructional techniques; refresher training in the subject matter.

Integrated software management. Integrate the software engineering and management activities into a coherent, defined software process that is tailored from the organization's standard software process and related process assets.

Knowledge and skills: methods and procedures for software estimating, planning, and tracking based on the project's defined software process; methods and procedures for identifying, managing, and communicating software risks.

Intergroup coordination. Establish a means for the software engineering group to participate actively with the other engineering groups so the project is better able to satisfy the customer's needs effectively and efficiently.

Knowledge and skills: building teams; managing teams; establishing, promoting, and facilitating teamwork; group dynamics.

Peer reviews. Remove defects from the software work products early and efficiently; develop a better understanding of the software work products and of the defects that can be prevented.

Knowledge and skills: types of peer reviews; objectives, principles, and methods of peer reviews; roles of reviewers; estimating the effort for preparing and participating in peer reviews.

Level 4 KPAs focus on establishing a quantitative understanding of both the software process and the software work products being built.

Quantitative process management. Control the process performance of the software project quantitatively.

Knowledge and skills: modeling and analyzing the software process; selecting, collecting, and validating process measurement data; applying basic quantitative methods and analysis techniques (e.g. estimation models, Pareto diagrams, and control charts); understanding the goals and value of quantitative process management.

Software quality management. Develop a quantitative understanding of the quality of the project's software products and achieve specific quality goals.

Knowledge and skills: planning quality commitments and goals for the product; measuring product and process quality; controlling product quality using the defined software process; understanding the goals and benefits of quantitatively managing product quality; collecting measurement data; understanding the quality measurements for the software process and product; planning and controlling the quality of the software product.

Level 5 KPAs focus on implementing continuous and measurable software process improvement.

Defect prevention. Identify the causes of defects and prevent them from occurring.

Knowledge and skills: defect prevention methods; conduct of task kick-off meetings; conduct of causal analysis meetings; statistical methods (e.g. cause/effect diagrams to determine root causes and Pareto analysis to set priorities for action proposals).

Technology change management. Identify beneficial new technologies (i.e., tools, methods, and processes) and transfer them into the organization in an orderly manner.

Knowledge and skills: technology transfer and change management; principles of statistical quality control.

Process change management. Continually improve the software process used in the organization with the intent of improving software quality, increasing productivity, and decreasing the cycle time for product development.

Knowledge and skills: managing technological and organizational change; team building; teamwork skills as applied to continuous process improvement; principles of quality and process improvement; procedures for proposing process improvements; benchmarking and comparative evaluation; setting and tracking goals for process improvement; motivation and team building in an environment of continuous improvement.

6.3.2 The Organization Process Category of SPICE

The organization process category of the SPICE BPG consists of processes that establish the business goals of the organization and develop process, product, and resource assets to help

the organization achieve its business goals. These organizational processes build organizational infrastructure, take the best of what is available in any one part of the organization, and make it available to all [SPICE-BPG 94].

The processes, and their base practices, are as follows:

Engineer the business. Establish strategic vision; deploy vision; establish quality culture; build integrated teams; provide incentives; define career plans.

Define the process. Define goals; identify current activities, roles and responsibilities; identify inputs and outputs; define entry and exit criteria; define control points; identify external interfaces; identify internal interfaces; define quality records; define process measures; document the standard process; establish policy; establish performance expectations; deploy the process.

Improve the process. Identify improvement opportunities; define scope of improvement activities; understand the process; identify improvements; prioritize improvements; define measures of impact; change the process; confirm the improvement; deploy improvement.

Perform training. Identify training needs; develop or acquire training; train personnel; maintain training records.

Enable reuse. Determine organizational reuse strategy; identify reusable components; develop reusable components; establish a reuse library; certify reusable components; integrate reuse into life cycle; propagate change carefully.

Provide software engineering environment. Identify software engineering environment requirements; provide a software engineering environment; provide support for developers; maintain software engineering environment.

Provide work facilities. Provide productive workspace; ensure data integrity; provide data backups; provide building facilities; provide remote access facility.

7 Culture Change

"Understand the lay of the land in which process improvement must take place. Organizations are like jungles, they have a lot of interesting and sometimes dangerous animals hidden in the weeds." —customer view

It is widely recognized that organizational culture must change to enable the implementation and institutionalization of process improvement.

Organizational culture includes shared values, beliefs, and understandings. It indicates which values members of an organization should adopt in order to behave consistently with organizational goals.

We begin by describing the general nature of a quality culture and selected new organizational paradigms. Then we describe general culture change concepts and some strategies that can be used to bring about change.

7.1 Directions

7.1.1 The Nature of a Quality Culture

What is the nature of a quality culture? It is typically characterized by the following features:

Shared quality-based values and goals. Customer focus, obsession with quality, teamwork.

Open communication paths. Access to information, stating opinions without fear, listening with respect, constructive conflict, negotiated agreements for work and relationships.

Productivity improvement. Understanding the value of measurement, actively working to improve processes.

Customer value. Continuously increasing value to external and internal customers.

ISO 9004-4 describes the environment considered essential for quality improvement [ISO9004-4 93]. This environment includes the following:

Management responsibility and leadership. To communicate purpose and goals; to continuously improve their own work processes; to foster open communication, teamwork and respect; to enable and empower everyone to improve.

Values, attitudes, and behavior. Satisfy customer needs; involve entire supply chain in quality improvement; demonstrate management commitment, leadership, and involvement; quality improvement is part of everyone's job, either by teamwork or individual activities; address problems by improving processes; continuously improve all processes; establish open communication with access to data and information; promote teamwork and respect for the individual; make decisions based on analysis of data.

Quality improvement goals. Establish quality improvement goals; integrate them with overall business goals; make them measurable, understandable, challenging, pertinent, agreed to by all, regularly reviewed, reflective of changing customer expectations.

Communications and teamwork. Open communication; teamwork; trust; removal of organizational and personal barriers that interfere with effectiveness, efficiency, and continuous improvement of processes.

Recognition. Encourage actions consistent with values, attitudes, and behavior necessary for quality improvement; emphasize development and growth of individuals; emphasize group performance and group recognition; encourage frequent and informal feedback; make reward systems consistent with recognition; do not promote destructive internal competition.

Education and training. All members of the organization should be educated and trained in quality principles, practices, and methods for quality improvement; training programs should be consistent with quality principles and practices; effectiveness of education and training should be regularly assessed.

7.1.2 New Organizational Paradigms

"The organizational culture must allow/encourage change." —customer view

Organizations must deal with complexity and change to achieve competitive advantage. New organizational paradigms are emerging that embrace change and improvement [Rensch 92]. They are based on shared vision, shared values, people orientation, employee involvement, and new management and leadership styles - essential elements in a process improvement corporate culture. Two examples are offered here [Senge 90], [Peters 87]. Others are referenced in the Appendix.

7.1.2.1 Learning to be a *Learning Organization*

"The organizations that will truly excel in the future will be the organizations that discover how to tap people's commitment and capacity to learn at all *levels in an organization." —Peter Senge*

The core disciplines. Personal mastery, mental models, shared vision, team learning.

The fifth discipline. Systems thinking.

Learning. Examining successes and failures; experimentation, observation, analysis; responding to a wide variety of different alternatives; making inquiry and commitment to truth the norm; challenging the status quo; motivating people to learn, and thus improve [Senge 90].

7.1.2.2 Thriving on Chaos

"If it ain't broke, you just haven't looked hard enough. Fix it anyway." —Tom Peters

Creating total customer responsiveness, pursuing fast-paced innovation, achieving flexibility by empowering people, and learning to love change creates a new view of leadership at all levels; building systems for a world turned upside down [Peters 87].

7.1.3 Leadership and Management

"Institute leadership." —W.E. Deming

"...unless the organization's executives are ready and willing to support the change efforts (through their altered management practices) it might be a disappointing exercise for those who so want to implement change..." —a change agent

"We will assure strategic clarity and consistency; we will provide visible supportive management practices, commitments, and leadership; we will set quality objectives and measurement standards; we will establish an environment so each person can be responsible for quality." —XEROX [XEROX 86]

New and changing roles are being defined as organizations shift towards a quality culture. An essential part of organizational change consists of augmenting management skills to meet changing needs. Management roles will change; leadership will emerge at all levels of the organization.

Predominant themes are summarized below.

Management responsibility and leadership. To communicate purpose and goals; to continuously improve their own work processes; to foster open communication, teamwork and respect; to enable and empower everyone to improve.

Leadership responsibilities. To promote thinking and acting at all levels of the corporation; to aspire to serve; to learn who lies outside the system thus needing help or deserving recognition; to improve the system; to accomplish consistency of performance within the system.

Leadership skills. Ability to build shared vision; to surface and challenge prevailing mental models; to foster systematic patterns of thinking; to enable people to expand their capabilities and shape their futures.

Management style. Open style with clear and consistent objectives that encourage group-derived continuous improvement.

Role of manager. Communicate, consult, delegate, coach, mentor, remove barriers, and establish trust.

Rewards and recognition. Individual and group recognition and rewards; negotiated criteria; sustaining the improvement effort.

Emerging management competencies. Reading the environment; active management; leadership and vision; empowering human resources; promoting creativity, learning, and innovation; skills in remote management; using information technologies; managing complexity and ambiguity; broadening competencies and reframing contexts.

Teams as the basic organizational building block. Train them, recruit for them, reward them, foster cooperation, change the role of middle management.

Required middle management changes. From scheduler to coach; from enforcer to facilitator; from vertical to horizontal focus; from transmitting top management needs down to selling teams' ideas up; from providing ideas down to helping teams develop their own ideas.

7.1.4 The People Management Capability Maturity Model

The People Management Capability Maturity Model v.0.2 (draft for public review) is a maturity framework that describes the key elements of managing and developing the talent of an organization. This framework includes key process areas pertaining to organizational culture, values, and teamwork [Curtis 94]. These (selected) key process areas are as follows:

People management values development. Create a culture that values the talent of the organization and supports the implementation of advanced people management practices.

Compensation and reward. Motivate each staff member to maximize their contribution and value to the organization.

Participatory culture. Incorporate the knowledge of staff members into decision-making processes.

Team building. Capitalize on opportunities to create teams that maximize the integration of diverse knowledge and skills to best perform a business function.

7.2 Change Concepts

"...[our major problem is] ... resistance to change, changes needed in management and practitioner paradigms, typical dysfunctional interrelationships and communications modes." —a change agent

7.2.1 Corporate Culture

For each organization, the nature of its desired culture ("Who are we?") must be established before change can take place. Leaders must recognize the importance of corporate introspection.

Creating and projecting a vision. Who you are and what you value.

Guiding beliefs. The target of how things ought to be: defining corporate roots, principles, philosophical foundations; determining why the organization exists.

Corporate strategy. Establishing what an organization wants to accomplish.

Daily beliefs. How things are, actual behaviors, rules and survival kits.

Linking. Guiding beliefs, strategy, and daily beliefs.

7.2.2 Technology Transfer

Technology transfer is the utilization of knowledge [Glaser 83]. This knowledge may pertain to a vision of the corporate culture, a process improvement method, or a specific software engineering tool. The idea is to put that knowledge into practice.

There are factors that influence the likelihood of technology adoption or adaption (and behavioral models of change) and they are important concepts for those involved in culture change.

Variables influencing acceptance of change. Relative advantage, compatibility with values, comprehensibility, practicability, demonstrability and trialability, championship (advocacy by influential persons), appropriateness of timing and circumstance.

Personal and social influences. Psychosocial considerations, economic and social status, professional qualities, personality and role of the leader, psychological attributes, resistance to change.

Organizational factors. Organizational climate and quality of worklife, organizational goals, organizational structure, organizational communication and decision making, organizational dynamics, organizational behavior, the power and pitfalls of the "hidden" organization.

Political, economic and sociocultural processes.

Organizational paradigms. Closed, random, open, synchronous [Constantine].

General strategies for achieving change. Coercive, normative, utilitarian, empirical-rational, normative-reeducative, power-coercive, persuasive, individual-change, data-based, organizational development, direct-action, manipulative, facilitation.

Key aspects of technology transfer. Context analysis (social and technical aspects of the environment, frames of reference); mapping (determining whether a technology is likely to succeed in an organization); boundary spanners (people who perform the mapping process).

7.2.3 Organizational Change

Stages of commitment to organizational change. Contact, awareness, understanding, positive perception, installation, adoption, institutionalization, internalization.

Characteristics of the change process. Unfreezing (discovering and accepting the need for change); transition (moving from current state to a more desirable state); refreezing (changes become routine organizational behavior, refocus on the product rather than the process).

Transition management. Unfreezing the present state, refreezing the desired state; drivers of change: opportunity, need, discomfort, pain; transition phases: contact, awareness, understanding, installation, adoption, institutionalization; communication and reinforcement tactics.

Resistance. Resistance patterns: uninformed certainty, informed doubt, realistic concern, informed certainty, stunned paralysis, denial, anger, bargaining, fear, depression, exploration, acceptance; assessing resistance; managing resistance; dealing with resistance.

Roles and responsibilities. Sponsors, targets/contributors, change agents, champions; visionary leadership.

Communication. Frames of reference; the Myers-Briggs Type Indicator; Wilson Learning.

Culture. Behaviors, values, unwritten rules; culture assessment: barriers and leverage points.

7.3 Change Strategies

"Our culture rewards the fire fighter. How can others want to improve, when fire fighting is rewarded?" —customer view

"When customers demand process improvement, organizations will respond." —customer view

There are several approaches to bringing about culture change. An organization must choose the most suitable approach. There are many approaches to understand and evaluate. A synthesis of various approaches may be most suitable depending on organizational needs. We selected a few for inclusion here. Others are referenced in the Appendix.

7.3.1 Adapting Process Improvement Approaches

Culture change can be viewed as a process improvement endeavor that uses the same steps and activities described in Section 6. The main differences are that the mechanisms used to improve the culture deal with behavioral change rather than process change, i.e., the way the people carry out worklife processes is changed rather than the worklife process itself.

This generic approach might entail the following steps: initiating the culture change effort (including establishing vision and goals), baselining the current culture and determining culture gaps, establishing priorities and action plans (including measures) for changing selected parts of the culture, implementing the plan within a pilot area of the organization, reviewing/revising based on pilot results, deploying the change throughout the organization, assessing results of that culture change effort, and recycling through next culture change areas.

Actions may result in training on culture issues, enhancing managerial skills, or establishing new rewards and recognition systems.

7.3.2 The Managing Technological Change System

The Managing Technological Change system is a structured approach to managing the human elements that are critical to achieving strategic business objectives. The eight components of the approach are designed to: collect information about the target organization with respect to an implementation effort, assemble the data, and build an implementation plan that will increase the likelihood of success [Myers].

> **Eight components of Managing Technological Change.** Project overview, implementation history assessment, sponsorship assessment, target resistance assessment, culture assessment, change agent assessment, assessment review, implementation plan.
>
> **Implementation plan components.** Assessment analysis, preliminary planning, diagnostics, key roles, sponsorship, change agent development, reinforcement, communication, target resistance, cultural resistance, monitoring and tracking.
>
> **Manage the human elements of change.** Identify change barriers; assess skills and motivation of key stakeholders authorizing and reinforcing the change; identify criteria for selecting and evaluating key players responsible for implementing change; identify potential for and sources of resistance; develop and apply strategies and tactics to drive change; develop effort estimates for the change.

7.3.3 Streams of Activity Model (Joiner Associates)

This approach identifies five streams of activities that are parallel, unending, and address all underlying elements that must be present for a successful improvement effort. These activities are as follows [Joiner 89]:

> **Support culture**, climate, and environment.

Improve performance through quality management.

Review through quality management.

Develop internal resources.

Build education and training community.

7.3.4 Logistics Management Institute—Continuous Improvement Process

This model focuses on organizational and behavioral change needed to instill and sustain a culture of continuous improvement. The objective is to establish a perpetual and total commitment to quality, and to involve everyone. Adaptations of this model exist at the process and individual level (See Section 5.) [Mansir 89].

Envisioning. Develop vision, build awareness, evolve mission statement, establish steering committee.

Enabling. Develop top management commitment, shape environment, provide resources, empower the organization.

Focusing. Establish goals, deploy goals and policy, involve customers and suppliers.

Improving. Define and standardize processes, assess process performance, improve processes, measure progress.

Learning. Identify needs, obtain materials, develop learning methods, train and educate everyone just in time.

Team building. Form teams in accordance with goals, integrate natural work groups, form cross-functional teams, pursue process improvement activities.

7.3.5 Establishing a Personal Improvement Culture

Some approaches to individual process improvement were described in Section 5.7. We include one more example of a bottom-up approach to process improvement that starts with the individual, and works up through groups and then to top management.

This approach advocates using quality tools to improve your own processes, extending this approach to groups, and then approaching management [Forsha 92].

Personal change is first. Using quality tools for personal change.

Group change is next. Developing relationships: communicating with personal integrity, self-respect, respect for others, understanding needs; interpersonal communication.

Changing management attitudes is next. Recognizing behavior styles; communicating; selecting early doable projects; creating a positive track record; creating awareness of the need for change; prioritize, provide vision of expected results; establish and monitor indicators; redefinition, coalition, and merging of views; salesmanship; negotiation; working with subordinates, peers, and management for consensus; overcoming barriers.

Techniques and skills to use.

Quality improvement process. Problem identification, problem analysis, planning, data collection, data interpretation, action, appraisal.

Quality tools. Concept development tools. These tools are used to start the change process, to generate ideas, to narrow them down, to derive a statement of direction: brainstorming, checklist, five whys, rating systems, prioritizing and the decision matrix, visualization, flowchart, the objective statement (who, what, when, where, how, plus success measures).

Behavioral styles. Thinker, director, socializer, relator; understanding and dealing with different types of social behavior.

8 Process Improvement Tools and Techniques

Tools and techniques for process improvement are emerging as the topic itself is evolving. Many of the tools of quality are applicable to software process improvement. Research in process centered software engineering promises to provide new tools and methods. In this section we describe tools and techniques that can be used in carrying out process improvement activities.

8.1 Customer Value

A process improvement culture focuses on the customer.

8.1.1 Customer Value Determination

Customer Value Determination is used to find out what your customers need and want; to find out what your competitive advantages are; to obtain your customers' views regarding where you need improvement [Stahl 91].

> Techniques for projecting, challenging, discovering, and confirming net customer value for your business.

8.1.2 Quality Function Deployment

Quality Function Deployment (QFD) is used to build quality products while reducing cycle time [Zultner 92], [Thompson 89].

> How to deploy customer value information into products so they meet/exceed customer net value targets: the House of Quality.

8.1.3 The Wheel of Improvement

The Total Quality Control (TQC) wheel portrays core skills and methods needed for improvement, and explains their use in relation to the achievement of the organization's improvement goals [King 89].

> **Center of wheel**. Customer Driven Master Plan: a 5-10 year strategic plan surrounded by three systems plus their supporting techniques and methods.
>
> **Daily control system**. Supported by statistical methods, work groups TQC Circles, standardization.
>
> **Hoshin planning system**. Supported by continuous improvement, vertical teams, and the seven "M" tools.
>
> **Cross functional management system**. (Quality, Cost, Delivery, Profit/Product). Supported by quality assurance/quality function deployment; horizontal customer/supplier teams; information system; audit tools.

8.2 Problem Solving

Problem solving involves problem definition (distinguishing between causes and symptoms) and decision making (analyzing the problem to identify solutions and choosing among them). Several tools and techniques are available for solving process problems [Brassard 89], [Imai 86], [Kan 92], [Scholtes 88].

8.2.1 Data Gathering

Problem solving often requires data collection as a first step. Typical data gathering tools are the following:

Interviews. Structured or unstructured; telephone or face-to-face.

Brainstorming. Structured or unstructured.

Nominal Group Technique

Focus groups. Structured group interviews; can use group data gathering tools such as brainstorming, nominal group technique.

Surveys. Formal or informal.

Observation.

8.2.2 Analytical Problem Solving (The Seven Tools)

These tools can help teams diagnose and solve quality improvement problems. Also known as *the seven statistical tools*, *the seven quality control tools*, and *the Q seven*, they are used when data are available and the task is to analyze the data to solve a particular problem [Imai 86]. The seven statistical tools used for analytical problem-solving are:

Pareto diagrams. These diagrams illustrate the frequency or effect of problems. The problem data are charted according to frequency or effect in decreasing order using a bar-graph format. These diagrams help to determine the order in which to solve problems by drawing attention to the *vital few* truly important problems.

Cause-and-effect diagrams. Also called *fishbone* and *Ishikawa* diagrams due to their appearance and originator, respectively, these are used to analyze the characteristics of a process or situation and the factors that contribute to them. They represent the relationship between some *effect* and possible *causes* influencing that problem or condition.

Histogram. A histogram graphically represents the measurement data on a bar chart. It reveals the amount of variation within process data and can be used to study the distribution of the problem data.

Control chart. A control chart is used to discover how much variability in a process is inherent (due to common causes or random variation) and how much is due to special causes (unpredictable individual actions). A control chart is the same as a run chart in that it displays observations over periods of time, but the control chart has statistically determined upper and lower control limits.

Scatter Diagram. A scatter diagram is used to display what happens to one variable when another variable changes. It is used to test the theory that the two variables are related and to study possible relationships between variables. A scatter diagram has a horizontal axis to represent the measurement values of one variable, and a vertical axis to represent the measurement of the second variable.

Graphs. There are many kinds of graphs or charts that can be employed, depending on the shape desired and the purpose of analysis. Bar graphs compare values via parallel bars; line graphs illustrate variations over time; circle graphs or pie charts indicate percentage breakdown of values (slices of the pie).

Checksheets. These are designed to record and tabulate data by using simple checkmarks to indicate situations or events. Checksheets answer the question "How often are certain events happening?"

8.2.3 Design Problem Solving Tools (The New Seven)

Design problem solving is used when data are not available or data is subjective and there is a need for collaboration among people [Imai 86]. They may be used to plan for the quality and design of new processes or to reengineer existing ones.

These seven quality control tools are sometimes referred to as *the NEW Seven* or *the 7 M tools* for group design, planning, and management.

Relations diagram (or relationship chart). This diagram shows the interrelationships in a complex situation (one that involves many interrelated factors) and clarifies the cause-and-effect relationships among factors.

Affinity diagram. This method is applied to a brainstorm result or to group work in which the ideas are grouped by subject matter, and it organizes and realigns the data.

Tree diagram. This is an extension of the value engineering concept of functional analysis and it shows the interrelationships among goals and measures.

Matrix diagram. This format is used to show the relationship between two factors.

Matrix data-analysis diagram. This diagram is used when the matrix chart does not provide sufficiently detailed information.

Process decision program chart (PDPC). This is used to decide the critical things to do first to improve a process. Because implementation programs to achieve specific goals do not always follow their plans, and because unexpected developments are likely to have serious consequences, PDPC has been developed not only to arrive at the optimum conclusion but also to avoid surprises.

Arrow diagram. This uses a network representation to show the steps necessary to implement a plan.

8.2.4 Other Problem Solving Tools

In addition to the 14 tools listed above, there are a number of other problem solving and decision making tools [Brassard 89].

Flowchart. A flowchart is a pictorial representation showing all of the steps of a process. Flowcharts are widely used for problem identification in a process called IMAGINEERING. The people with important knowledge about the process meet to: draw a flowchart of what steps a process actually follows, draw a flowchart of what steps the process should follow, then compare the two charts.

Process capability. Process capability is used to determine whether the process, given its natural variation, is capable of meeting established (customer) specifications.

Force Field Analysis. Force Field Analysis is used to analyze two opposite condition or situations.

Group problem solving to reach consensus. (See Section 9.)

8.3 Statistical Techniques

Statistical methods have broad applications in determining and monitoring process improvement activities. Statistical data analysis is used to transform data into useful information for decision making. Commonly used statistical techniques used in process improvement are as follows:

Design of experiments. Design of experiments is an analytical technique that enables testing of many factors in each experiment and thus helps identify which variables have the most influence on the overall outcome. It refers to the structure of an experiment, with particular reference to: (a) the set of treatments included in the study, (b) the set of experiment units included in the study, (c) the rules and procedures by which treatments are assigned to the experiment unit, and (d) the measures that are made on the experimental units after the treatments have been made.

Sampling. Sampling involves identifying the population of experimental units and developing a scheme that selects a subset of the population in such a way that each experiment has an actual chance of being in the subset chosen. The subset is referred to as a simple random sample (in this case). A stratified random sample is produced by applying a population sampling scheme to each stratum.

Statistical data reduction tools. Mean, median, range, standard deviation, correlation, regression, and chi-square.

Graphical data reduction techniques. Two- or three-dimensional plots, bar charts, pi charts, etc.

Statistical process control. The premise of statistical process control is that data variations fall into two categories: those that are endemic to the system and the processes in place (*common* causes of variation), and those that are due to specific circumstance such as lack of understanding of operators or defective equipment (*special* causes of variation). The two types of data are separated by plotting all data on a run chart and calculating control limits. Data that are between the upper and lower limits represent variations due to process and data above the upper limit and below the lower limit represent special causes of variation.

Robust statistics.

Box plot.

8.4 Cost/Benefit Analysis

Measuring the benefits of process improvement is itself a process [Rozum 93]. The software process improvement benefit index recommended by SEI is the ratio of dollars saved [(cost(old) - cost(new)] divided by the old cost.

Software process improvement cost. There are two types of cost associated with a process improvement program: nonrecurring cost, and recurring cost. Nonrecurring cost includes consultants, training, standards change, planning, pilot testing, and implementation. Recurring cost includes overhead, error prevention, process monitoring, error-detection, etc.

Measuring savings. The amount of money saved can be calculated by quantifying the dollar value of items such as: increased productivity, early error detection and correction, overall reduction of errors, improved trends in maintenance and warranty work, elimination of processes or process steps.

Processes can be analyzed quantitatively by means of various costing methods such as activity-based costing (ABC). Under ABC, costs can be assigned to process activities to facilitate decision making for investment justification and process management [Elzinga 95], [Jeans 89].

8.5 Risk Assessment Techniques

Risk assessment consists of risk identification (determining which risk events are likely to affect the process improvement project), risk quantification (evaluating the range of possible outcomes and their likelihood of occurrence), and risk mitigation (defining steps for mitigation).

Risk identification tools. Checklist, historical results, interviewing.

Risk quantification tools. Expected monetary value, statistical sums, schedule simulation, decision trees.

Risk mitigation tools. Contracting, contingency planning, alternative strategies, insurance.

8.6 Defect Detection and Prevention

Defect prevention is a systematic way of reducing the number of defects in a work product. This goal is achieved by deploying a process that does not introduce defects in the first place.

First, defects must be detected. Peer reviews can be used to identify defects and to help understand the types of defects that can be prevented. Two commonly used peer review techniques are inspections and walkthroughs.

Inspections. Inspections follow a formal process with defined roles, activities, and deliverables. Statistics are recorded on defects detected and detection rates. Defects are later corrected.

Walkthroughs. Walkthroughs are a less formal type of inspection intended to provide constructive feedback to improve the product being reviewed.

After defect data are available, problem solving methods such as cause-and-effect diagrams and Pareto diagrams can be used to determine root causes of the defects and to set priorities for methods to prevent them from occurring.

8.7 Benchmarking

Benchmarking is a technique used to improve an organization by comparing what that organization does to what others do. It involves measuring products, services, and/or practices against tough competitors or recognized leaders, and developing plans to adopt the best practices found [Shattuck 93].

Benchmarking process. Planning (identify benchmarking subject, identify benchmarking partners, determine data collection method, collect data); Analysis (determine current competitive gap, project future performance); Integration (communicate findings and gain acceptance, establish functional goals); Action(develop action plans, implement plans and monitor progress); Maturity (recalibrate benchmark).

Types of benchmarking. Internal, competitive, functional, strategic/performance, process/functional, product.

8.8 Process Definition

Processes are defined so people in organizations understand their roles, responsibilities, dependencies, and how to do business. A process definition document is wrapped around a process model and its purpose is to guide the developers in performing their tasks. A process definition document is analogous to a *play book* employed by a professional team. It describes what, who, when and why surrounding a task that needs to be done.

Descriptive process model. A detailed and formalized representation of software life-cycle activities that is characterized by a set of notations to represent objects, transforms and events.

Process representation notations. There are a number of notations for process representations. They are either text-based notations or a combination of graphics and text. A process is viewed from a number of perspectives: functional (indicates process steps); organizational (shows who/what performs each function); behavioral (identifies what the process states are); informational (depicts the information structure and the information relationships). Currently there is not one notation that is equally strong in representing a process from all perspectives. Some commonly used notations are:

State Transition Diagrams (STDs). STDs are used for finite state machines. Any process that can be described in terms of a finite automaton can be represented using an STD. Finite state machines provide a possible representation for modeling sequences of events within some defined domain.

Entry-Task-Validation-Exit (ETVX). ETVX is a quasi-diagrammatic representation identifying entry criteria, tasks to be performed, validation requirements, and exit criteria.

Structured Analysis and Design Technique (SADT). The SADT approach involves identifying activities, and then: identifying the input and output of these activities, identifying factors that constrain the activities, and identifying resources and materials that support the activities.

Statecharts. Statecharts allow a finite automaton to be decomposed into representations that model two or more interacting or communicating subsystems.

Petri nets. Petri nets have been used to model manufacturing processes, chemical processes, and hard real-time embedded processes. An important characteristic of Petri nets is that they capture the dynamic behavioral characteristics of systems being modeled. In addition to graphical notation, Petri nets also come with a significant body of mathematical formalism.

Process Automation Tools. Process automation tools provide a way to integrate people and methods in a software development organization. There is currently little practical day-to-day experience with this emerging technology. However, its maturation promises to enhance process improvement. Some of the tools being researched for process automation include Process Weaver, Synervision, and Statemate.

8.9 Process Measurement

Process measurement is used to identify candidate processes for improvement and to track process improvement efforts. Defining key measurement points and deriving quantifiable proof of process improvement are the reasons for measurements.

Metrics paradigms. Basili's Goal-Question-Metric (G-Q-M) framework provides a tool for organizations to decide which measurements to collect. It links process goals with the critical questions that must be answered to achieve the goals, and identifies data items needed to collect measurement [Basili 84].

Checklists approach. The SEI has developed an approach for design and implementation of a measurement program based on a checklist paradigm and Basili's Goal-Question-Metric framework.

Size planning concepts. Tools used to estimate size at the early stage of requirements definition are: Fuzzy-Logic, Function-Point, Standard-Component, Change Sizing.

Cost estimating models. There are a number of models available to estimate software cost, including: induction models, parametric models, COCOMO, SLIM, PRICE, function points, ESTIMACS.

Metrics baseline. The four core measures of software are size, effort, schedule, and quality. Size is measured in terms of lines of code or function point. Effort is expressed in terms of staff hours or dollars. Schedule is expressed in terms of time (days, weeks, months, or years). Quality is expressed (in a narrow sense) in terms of defects: the lower the number of defects the higher the quality of the software. Software quality generally deals with many more attributes than just defects.

Quality attributes. Quality attributes are determined by audits, reviews, trouble reports, and defect detection. Quality factors include functionality, usability, reliability, maintainability, supportability.

9 Pervasive Supporting Skills

In this section we describe general skills that can be applied in many process improvement situations and activities. Sometimes referred to as *people* skills, many of these areas form a necessary foundation for the quality culture described in Section 7. Our customers, through surveys and focus groups, have cited people-related skills as a major area in which organizations need competency in order to effect process improvement.

> *"People don't know how to address human issues, or don't even acknowledge human issues are there." —customer view*

9.1 Teamwork Skills

> *"Organize as much as possible around teams, to achieve enhanced focus, task orientation, innovativeness, and individual commitment." —Tom Peters*

> *"As organizations become more involved in the quality movement, they discover the benefits of having people at all levels work together in teams." —The Team Handbook*

The process improvement infrastructure involves many teams: the steering committee, the process group, and process action teams. Teamwork skills are an essential part of process improvement, and teamwork forms one of the bases of a quality culture. Selected teamwork topics are described below, and the references offer elaboration.

9.1.1 Managing Group Processes

Whether they are called quality circles, semi-autonomous work groups, self-directed teams, or self-managing teams, teams are groups of people working together. Teams use group processes, meet in group sessions, and behave to maximize group participation and contribution.

Ingredients for a successful team. Clarity in team goals, an improvement plan, clearly defined roles, clear communication, beneficial team behaviors, well-defined decision procedures, balanced participation, established ground rules, awareness of the group process, use of the scientific approach.

Planning group sessions. Purpose and desired outcome; is a group needed? Who should attend? Gauging group chemistry; agenda building; meeting roles.

Planning the group process. Getting people involved; sharing and processing group information; group presentations; subgroup work.

Group task behaviors. Proposing, building, information seeking, opinion seeking, information giving, opinion giving, disagreeing, summarizing, testing comprehension, consensus building.

Group maintenance behaviors. Encouraging, harmonizing, performance checking, standard setting, tension relieving.

Gate-keeping processes. Regulating group participation by bringing in and shutting out.

Team selection. Cross-functional teams.

Team roles. Leader, facilitator, technical expert, quality advisor, team members, enabler; role assignments; role switching; role sharing.

Facilitation. Focusing, stimulating contributions, dealing with disruptive behavior.

Team performance assessment. Rewarding collaborative teamwork.

9.1.2 Team Building

Teams progress through various phases as they develop and grow. Two models are described below.

Stages of Team Growth. Forming (transition from individual to team member); Storming (resistance, defensiveness, competitiveness); Norming (reconciliation, establishing and accepting ground rules, cohesiveness, trust); Performing (team understanding, satisfaction, constructive self-change, ability to prevent or work through group problems, closeness) [Scholtes 88].

Team Performance Model. Orientation (Why am I here?); Trust Building (Who are you?); Goal/Role Clarification (What are we doing?); Commitment (How will we do it?); Implementation (Who does what, when, where?); High Performance (Wow!); Renewal (Why continue?) [Drexler 92].

9.1.3 Team Dynamics

Teams must learn to work together and support each other. They must interact constructively and resolve group conflicts.

Dealing with emotions. Acknowledging feelings; processing feelings; refocusing on outcomes.

Guidelines for constructive feedback. Acknowledge the need for feedback, give both positive and negative feedback, understand the context, know when to give feedback, know how to give feedback, know how to receive feedback.

Working through group problems. Methods: off-line conversation, impersonal group time, off-line confrontation, in-group confrontation; negotiation; conflict resolution.

9.1.4 Group Decision Making Techniques

Several decision making approaches are possible such as autocratic (leader decides), collaborative (group discusses, leader decides), delegative (decision is delegated), and consensus.

Consensus is reached when there is a group decision that all members can support and no member opposes. Each person understands the decision, has had a chance to express his or

her view, and states willingness to support the decision. There are several techniques that can be used to reach consensus.

Brainstorming and multivoting. Brainstorming: define the topic; think silently; call out ideas (no discussion); capture list of items generated. Multivoting: combine similar items; allow members to choose up to 1/3 of the items for consideration; repeat until only a few items remain.

Nominal Group Technique. Brainstorm to generate ideas, clarify and discuss; multivote to reduce list to 50 or fewer items; vote by assigning a point value to each item ranging from highest preference to lowest, highest value is 4 for up to 20 items, 6 for 20-35, 8 for 35-50 items, tally the votes, highest is the group's choice.

List reduction. Using filters (criteria) to shorten a list of ideas; balance sheets to identify and review pro's and con's of ideas; force field analysis.

Rating systems. Criteria rating forms; rating the criteria; applying criteria to problems or solutions; point scoring systems; weighted voting; paired comparisons.

Analytical hierarchy process. A tool to establish and prioritize goals, objectives, and alternatives [Saaty 80].

9.2 Communication Skills

"communications ... a vital process for promoting organizational learning, improvement, and change" —Mary Young and James E. Post

Communication is another key aspect of a successful process improvement effort. It is not only essential for carrying out process improvement activities, but open communication is a feature of a quality oriented corporate culture.

Communication involves exchange of information. Both sender and receiver have responsibilities to ensure the information is correctly understood. Communication occurs at several levels: corporate, team, and interpersonal.

9.2.1 Corporate Communication

Principles of effective corporate communications. Chief executive as communications champion; matching actions and words; commitment to two-way communication; face-to-face communication; shared responsibility for employee communications; dealing with bad news; customers, clients, and audiences.

Communications strategy. Communicate not only what, but why and how; timeliness; communicate continuously; link the "big" picture with the "little picture"; don't dictate the way people should feel about the news; uncover and remove barriers to communication.

Communications as a *process* (not a product). Send, encode, transmit across channel, decode, receive; feedback loops.

Communication channels. Videos, electronic mail, publications, television; writing, pictures, newsletters; formal or informal; written or oral.

Techniques. Opinion surveys, attitude surveys; techniques for effective communication of a vision.

Institutionalizing communications policies. Training, coaching, goal-setting, evaluation, reward, responsibility to communicate problems; establishing ground rules for surfacing and dealing with conflict.

9.2.2 Team Communication

These guidelines allow for clarity of discussions and information passing in team situations.

Speaking. Speaking clearly and directly (e.g. avoid using questions to disguise statements); being succinct without long anecdotes or examples.

Listening. Listening actively, exploring ideas.

Sharing information on many levels. Sensing statement, thinking statement, feeling statement, statements of intentions, statement of actions.

Effective discussion skills. Ask for clarification, act as gatekeepers to encourage group participation, listen and actively explore ideas, summarize and restate, contain digression, manage time, end the discussion when nothing further to be gained, test for consensus, evaluate the quality of the discussion.

9.2.3 Interpersonal Communication

At the individual level, effective communication ensures information is mutually understood and openly shared.

An individual needs writing skills, presentation skills, persuasion, active listening, questioning, body language, constructive criticism, conflict resolution, self awareness.

9.3 Interaction Skills

"Help people come to grips with human issues."—customer view

We capture here some skills used in everyday human interaction. Deimel describes early work in developing working models that facilitate mastery of human interaction capabilities [Deimel 94].

Interpersonal skills. Networking, negotiating, leadership, expediting, tact, being part of the solution and not part of the problem, confrontation.

Human dynamics. Mental, emotional, and physical principles; self-knowledge; different personality dynamics; human behavior models.

Human interaction capabilities [Deimel 94]:

skills: receptive communication, expressive communication, negotiation, collaboration, conflict management, decision making

activities: Teamwork, meetings, interviews, presentations, planning sessions, reviews, training

human interaction capability model—predominant relating styles: power differential/self-interest; formal protocol/enforcement; formal roles/team play; dynamic roles/public data; synergistic roles/shared goals

human interaction capability model—group attitudes: denial/co-dependency; awakening; awareness; confidence; certainty

9.4 Consulting Skills

"A consultant is a person in a position to have some influence over an individual, a group, or an organization, but who has no direct power to make changes or implement programs." —Peter Block

People working on process improvement frequently act as consultants and consulting skills become essential for influencing decision makers [CSW].

Phases of consulting:

entry, sensing, and relationship building: listening, building a trusting relationship, probing; referral mechanisms; questioning, advising, reflecting, interpreting, self-disclosing, silence

contracting: explicit agreement on mutual expectations, explicit agreement on working arrangement; essential wants and desirable wants; planning a contracting meeting; sample contract contents: goals, scope, team, roles, process, anonymity/confidentiality, termination, resources; renegotiation

data gathering, diagnosis, and feedback: data collection, analysis, presentation, decision making; interviews, questionnaires, observation, historical, sampling; data reduction, graphic presentation

planning, execution, and monitoring: develop project and monitoring mechanisms; select project planning method, milestones, resources, commitment; execute and monitor plan; types of plans (strategic, tactical, operational); planning tools (Pert, Gantt, CPM); actions and outcomes (best case, worst case); checkpoints (milestones, recontracting points) renegotiation strategy; replanning

evaluation and consultant feedback: effectiveness of consultant, lessons learned, extent to which project objectives met, post-project surveys; managing feedback meetings

termination: exchange feedback and terminate; leaving with a good relationship

Authenticity skills. Making "I" statements; stating present feelings; describing in a nonevaluative way; changing thoughts into statements.

Client resistance. Common forms of resistance; handling the resistance: pick up the clues, name the resistance in neutral language, make an authentic "I" statement, let the client respond.

Consultant roles. Technical expert, process facilitator; collaboration with client regarding roles of: objective observer, process counselor, fact finder, identifier of alternatives and linker of resources, joint problem solver, trainer/educator, information specialist, advocate.

9.5 Behavioral Change Skills

"We use two approaches to move our culture towards new ideas: change behaviors to change attitudes and change attitudes to change behaviors."
—SEPG member

Social Behavior. Understanding and dealing with different types of social behavior [Forsha 92].

mounting behaviors (expressing dominance and control): back stabbing, sniping, back-shooting, bullying, gatekeeping, back burner

grooming behaviors (extending friendship, warmth, and cooperation): Compliment, consideration, facilitation, integrity

manipulative behaviors: Alligator (rage), assumption, hidden agenda, lip service

Transactional analysis. Ego states: parent, child, adult; Karpman Drama Triangle: persecutor, victim, rescuer; games people play [Harris 69].

Strategies. Conflict resolution; constructive criticism; negotiation; contracting; managing stress; behavioral modeling; Aikado: using opponent's energy; knowing how to sell; reframing.

Rewards and recognitions. Identifying intrinsic and extrinsic rewards; informal and formal reinforcement mechanisms.

Self-awareness instruments. Myers-Briggs Type Indicator [Kroeger 92]; Wilson Learning.

Coaching. Coaching is a process for transferring knowledge, skills, and/or values and attitudes from the coach to the learner so that learner is enabled or empowered to perform new or increasingly more complex tasks [Mink 93].

10 Conclusions

10.1 Tailoring Considerations

This report has presented subject matter of the process improvement area. It has not indicated *who* must know *what* or to what extent. Process improvement requires teams of professionals with a diversity of knowledge, skills, and attributes. The synergy of individual competencies covering the broad range of topic areas described here is what will affect process improvement. To be effective however, certain fundamentals must be comprehended and shared by all.

Selecting subsets of the process improvement subject matter for specific audiences is primarily the responsibility of curriculum designers and skills analysts and we envision ongoing work to develop, gather, and disseminate recommendations from different contexts and domains. However, we offer some brief tailoring considerations here.

The subject matter may be tailored by general audience category. Table 5 depicts sample audiences for acquiring knowledge and skills across academic and industrial domains.

Table 5: General Audience Classification with Sample Audiences in Different Domains

General Audience Category	Context	
	Academic Domain	**Industry/government Domain**
Managers: Strategic and Tactical	Engineering Management Specialty students	Chief Executive Officers Software Managers Management Steering Committees Sponsors
Managers: Operational	All undergraduate and graduate students (core)	Project Managers Process Owners
Process Specialists	Process Engineering Specialty students Quality Improvement Specialty students	SEPG Members Change Agents Champions
Practitioners	All undergraduate and graduate students (core)	Process Action Teams Software Engineers Support Specialties Everybody

Using this general audience breakdown, we consider a very rough identification of which subject matter areas are most pertinent for which audience, and what extent of mastery might be required. In Table 6, each "x" represents more competency in the topic area, ranging from "x" (general knowledge and competency) to "xxx" (in-depth mastery).

Table 6: Aligning Subject Matter with General Audiences

Topic Areas	Audience			
	Managers Strategic and Tactical	**Managers Operational**	**Process Specialists**	**Practitioners**
Section 4: Process Fundamentals				
4.1 General Concepts	xx	xx	xxx	xx
4.2 Process Maturity Concepts	xx	xx	xxx	xx
4.3 Process Development and Enactment Concepts	xx	xx	xxx	xx
4.4 Process Modeling Concepts	xx	xx	xxx	xx
4.5 Process Definition Concepts	xx	xx	xxx	xx
4.6 Software Process Measurement	xx	xx	xxx	xx
4.7 Software Engineering Processes	xx	xxx	xxx	xxx
Section 5: Process Improvement Fundamentals				
5.1 Concepts and Principles	xxx	xxx	xxx	xxx
5.2 The Seeds of Process Improvement	xxx	xxx	xxx	xx
5.3 Improvement Models and Standards	xxx	xx	xxx	x
5.4 Process Appraisal	xx	xx	xxx	x
5.5 Improvement Approaches: Organizational Level	xxx	xx	xxx	x

Table 6: Aligning Subject Matter with General Audience

Topic Areas	Audience			
	Managers Strategic and Tactical	Managers Opera-tional	Process Specialists	Practi-tioners
5.6 Improvement Approaches: Process Level	xx	xx	xxx	xx
5.7 Improvement Approaches: Individual Level	xxx	xxx	xxx	xxx
Section 6: Process and Process Improvement Management				
6.1 Process Improvement Management	xxx	xxx	xxx	xx
6.2 Process Management	xx	xxx	xxx	xxx
6.3 Organizational Process Management	xxx	xx	xxx	xx
Section 7: Culture Change				
7.1 Directions	xxx	xxx	xxx	xxx
7.2 Change Concepts	xx	xx	xxx	xx
7.3 Change Strategies	xx	x	xxx	x
Section 8: Process Improvement Tools and Techniques				
8.1 Customer Value	xxx	xxx	xxx	xxx
8.2 Problem Solving	xxx	xxx	xxx	xxx
8.3 Statistical Techniques	xx	xx	xxx	xxx
8.4 Cost/Benefit Analysis	xxx	xx	xxx	xx
8.5 Risk Assessment	xxx	xxx	xxx	xx
8.6 Defect Detection and Prevention	x	x	xxx	xxx
8.7 Benchmarking	x	xx	xxx	xx
8.8 Process Definition	x	xx	xxx	xxx
8.9 Process Measurement	x	xx	xxx	xxx

Table 6: Aligning Subject Matter with General Audience

Topic Areas	Audience			
	Managers Strategic and Tactical	Managers Opera-tional	Process Specialists	Practi-tioners
Section 9: Pervasive Sup-porting Skills				
9.1 Teamwork Skills	xxx	xxx	xxx	xxx
9.2 Communication Skills	xxx	xxx	xxx	xxx
9.3 Interaction Skills	xxx	xxx	xxx	xxx
9.4 Consulting Skills	xxx	xxx	xxx	xx
9.5 Behavioral Change Skills	xx	xx	xxx	xx

10.2 Delivery Considerations

The subject matter of process improvement is interdisciplinary in nature, and we envision delivery of this material to be carried out through collaborative efforts.

In academia, several departments might be involved. For example, besides being taught by software engineering and computer science faculty, some topics may be taught in management, statistics, economics, industrial psychology, or other social science departments. Industry experts and quality consultants could augment regular course offerings.

In industry and government, collaboration with universities, consultants, and other organizations may help meet education/training delivery requirements.

As this subject area continues to mature, we anticipate that supporting materials will continue to be developed and disseminated to assist teaching and learning about process improvement.

10.3 Next Steps

This report is an initial compilation of information from a rapidly advancing field. We envision compiling or developing supporting educational materials for these topic areas at a later time. These may be in the form of curriculum models, detailed course syllabi, course notes, courses, curriculum modules, annotated bibliographies, best practice reports, or other guidelines.

Contact Information, on page vii, gives the address through which readers can send us inputs for enhancement, improvement, and further work in this area. We welcome your views.

"Over the long run, superior performance depends on superior learning."
—Peter Senge

Appendix A Sources and References

The sources used in preparing this document, plus selected additional reference materials are presented here in order of the sections in the report.

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Appendix B Contributors, Feedback from the Field, and Reviewers

B.1 Survey on Capability Maturity Model for Software (CMM)-Based Education and Training

This survey was carried out in 1992 and 1993. The purpose was to contact a broad base of SEI customers and elicit their views and concerns regarding several aspects of process improvement. This information has helped in the preparation and validation of some of the material in this report. Eighty-one responses were received. Respondents included subsets of Software Capability Evaluation (SCE) Workshop attendees, SEI Resident Affiliates, 1992 SEI Symposium attendees, participants in the 6th Conference on Software Engineering Education, West Coast Software Process Improvement Network (SPIN) members, Capability Maturity Model (CMM) Advisory Board members, participants in SEI's Software Project Management and Software Productivity Improvement courses, government contacts provided by SEI staff members, and SEI reviewers/consultants [Ibrahim 93a].

B.2 Software Process Improvement Curriculum: Birds-of-a-Feather Participants

A birds-of-a-feather session on "Software Process Improvement Curriculum" was held at the 7th Conference on Software Engineering Education (CSEE) in January 1994 in San Antonio, Texas. This session, led by Ron Radice and Linda Ibrahim, focused on discussing issues and topics that might be addressed in software process improvement education and training. A survey was conducted eliciting participants' views on topic areas and their relative importance for different audiences. The individuals in Table 7 participated in that session.

Table 7: Birds-of-a-Feather Participants

Name	Affiliation
Ted Ahmanson	Bell Atlantic
Shahrzad Amirsoleymani	Moorhead State University
Don Bagert	Texas Tech University
Stefan Biffl	Technical University of Vienna - Austria
Maribeth Carpenter	SEI
Marcus Deininger	University of Stuttgart, Germany
Janet Drake	University of Northern Iowa
Norm Gibbs	SEI

Table 7: BoF Participants

Name	Affiliation
Thomas Hilburn	Embry-Riddle Aeronautical University
Iraj Hirmanpour	Embry-Riddle Aeronautical University
Soheil Khajenoori	Embry-Riddle Aeronautical University
Peter Knoke	University of Alaska-Fairbanks
Russ McGuire	Cerner Corporation
Nancy Mead	SEI
Frederic J. Mowle	Purdue University
Pierre N. Robillard	Ecole Polytechnique - Montreal, Canada
Aboalfazl Salimi	Embry-Riddle Aeronautical University
Carol Sledge	SEI
Massood Towhidnejad	Embry-Riddle Aeronautical University
Laurie Werth	University of Texas at Austin
Sascha Zumbusch	Contributed Software - Berlin, Germany

B.3 Informal Questionnaire on Topic Areas

In the summer of 1994 an informal survey was conducted via selected bboards and email lists asking for views regarding knowledge and skills required for process improvement. The survey asked for ideas and thoughts along the following lines:

> **Topic:** Briefly describe a topic area you believe is important to be knowledgeable about in order to effect process improvement. Topics may range from broad concepts to specific skill areas.
>
> **Objective**: Please indicate the reason you need knowledge of these concepts or mastery of these skills in the context of process improvement.
>
> **Importance**: Please indicate whether you believe this is an "essential" topic or a "desirable" topic for process improvement education and training.

The individuals in Table 8 provided their thoughts and perspectives:

Table 8: Contributors Regarding Topic Areas

Name	Affiliation
Judy Bamburger	-
Richard Botting	California State University
Jim Cardow	TYBRIN Corporation
Janet Chamberlain	-
Mike Connelly	Tandem Computers, Inc.
Margie Davis	ADP Dealer Services
Dennis Frailey	-
Gary Gaston	Lockheed - Ft. Worth Co.
Terry Hinton	University of Surrey (England)
Arto Jarvinen	SoftLab ab (Sweden)
Sanjeev N. Khadilkar	Motorola India Electronics (Pvt.) Ltd.
Mike Kirby	Xerox Corporation
Jean M. MacLoed	Hewlett-Packard Co.
Pete Malpass	SEI
Mike Mattison	SEI
David E. McConnell	Naval Surface Warfare Center, Dahlgren Division
Mike McCracken	Georgia Institute of Technology
Julia L. Mullaney	Union Switch and Signal, Inc.
Mark Paulk	SEI
Margaret A. Ramsey	Software Process Innovators
Hal Render	University of Colorado at Colorado Springs
Joc Sanders	Centre for Software Engineering (Ireland)
Walt Scacchi	University of Southern California
Barry Shostak	CAE Electronics Ltd.
Peter Spool	Siemens Corporate Research, Inc.
Steve Wilkinson	Tandem Computers, Inc.

B.4 Symposium Focus Group

In August 1994 a focus group regarding "Knowledge and Skills for Process Improvement" was held in conjunction with the SEI Symposium. The group focused on answering the following question: "What are the main topics you have found necessary to know about or be skilled at in order to effect process improvement?" Additional discussion ensued regarding subtopics within these topics, audience for the subject areas, and the scope of process improvement for the purposes of this report.

Linda Ibrahim and Iraj Hirmanpour facilitated this session, and the people in Table 9 participated:

Table 9: Focus Group Attendees

Name	Affiliation
Neil Adams	Mitre Corp.
Maribeth Carpenter	SEI
Pat Delohery	HBO & Co.
Libby Dunn	Reliance Comm/Tec Transmission Systems
Pat Ferguson	Advanced Information Systems
David E. McConnell	Naval Surface Warfare Center, Dahlgren Division
Bob McFeeley	SEI
Dave Moore	RWD Technologies, Inc.
Paula Moore	National Oceanic & Atmospheric Administration, Dept. Of Commerce
Chuck Myers	SEI
Jeff O'Neil	PRC Inc.
Jerome Pesant	Applied Software Engineering Centre (Canada)
David K. Smith	Navy Fleet Material Support Office
Joyce Statz	TeraQuest Metrics, Inc.
Michael Stinson	SEI, Central Michigan University
Sarah Sullivan	-
Louise Williams	CACI

B.5 Reviewers

This report was reviewed internally for early drafts, internally and externally for an intermediary draft, and internally for the final draft. The reviewers in Table 10 participated.

Table 10: Reviewers

Name	Affiliation
Clark Archer	SEI, Winthrop University
Judy Bamberger	-
Peter Capell	SEI
Maribeth Carpenter	SEI
Bill Curtis	SEI
Robert Daniel	GeoQuest Data Management
Margie Davis	ADP Dealer Services
Betty Deimel	SEI
Suzanne Garcia	SEI
Joe Giannuzzi	SEI, Defence Contract Management Command
John Goodenough	SEI
Dan Green	SEI
Jon Gross	SEI
Bill Hefley	SEI
Fred Hueber	SEI
Watts Humphrey	SEI
Patricia Hurst	Fastrak Training Inc.
Soheil Khajenoori	Embry Riddle Aeronautical University
Mark Kusanic	SEI
Walt Lamia	SEI
Beth Leber	SEI
John Maher	SEI
David McConnell	Naval Surface Warfare Center, Dahlgren Division
Bob McFeeley	SEI

Table 10: Reviewers

Name	Affiliation
Nancy Mead	SEI
Bill Peterson	SEI
Dick Phillips	SEI
Ron Radice	SEI, Software Technology Transition
Russ Reed	SEI, Sematech
Barry Shostak	CAE Electronics Ltd. (Canada)
Becky Smith	RebL Systems
Mary Ellen Steibel	Delph Information Systems
Jim Stewart	SEI, Nuclear Regulatory Commission
Mike Stinson	SEI, Central Michigan University
Sarah Sullivan	-
Carol Ulrich	SEI
Laurie Werth	University of Texas, Austin
Rosie Wood	Stability, Inc.
Janet Yodanis	SEI
Dave Zubrow	SEI

Appendix C Improving the Education Process

"Institute a vigorous program of education and self-improvement." —W. E. Deming

Models and standards for improvement frequently include a process or process area dealing with education and training. Selected extracts from such guidelines are offered in this section in order to provide special focus on the educational process and its improvement.

C.1 CMM-Defined Level Key Process Area "Training Program"

Purpose: to develop the skills and knowledge of individuals so they can perform their roles effectively and efficiently

Goals: Training activities are planned. Training for developing the skills and knowledge needed to perform software management and technical roles is provided. Individuals in the software engineering group and software-related groups receive the training necessary to perform their roles. The key practices to accomplish these goals are as follows:

> **Commitment to perform**: The organization follows a written policy for meeting its training needs.
>
> **Ability to perform**: A group responsible for fulfilling the training needs of the organization exists. Adequate resources and funding are provided for implementing the training program. Members of the training group have the necessary skills and knowledge to perform their training activities (e.g. training in instructional techniques, refresher training in the subject matter).
>
> **Activities performed**: Each software project develops and maintains a training plan that specifies its training needs. The organization's training plan is developed and revised according to a documented procedure. The training for the organization is performed in accordance with the organization's training plan. Training courses prepared at the organization level are developed and maintained according to organization standards. A waiver procedure for required training is established and used to determine whether individuals already possess the knowledge and skills required to perform in their designated roles. Records of training are maintained.
>
> **Measurement and analysis**: Measurements are made and used to determine the status of the training program activities. Measurements are made and used to determine the quality of the training program.
>
> **Verifying implementation**: The training program activities are reviewed with senior management on a periodic basis. The training program is independently evaluated on a periodic basis for consistency with, and relevance to, the organization's needs. The training program activities and work products are reviewed and/or audited and the results are reported.

Source: Paulk; Weber; Garcia; Chrissis; & Bush. *Key Practices of the Capability Maturity Model, Version 1.1* (CMU/SEI-93-TR-25, ADA263432). Pittsburgh, Pa.: Software Engineering Institute, Carnegie mellon University, 1993.

C.2 SPICE Organization Process Category Process: "Perform Training"

Purpose: to provide the organization and projects with individuals who possess the needed skills and knowledge to perform their roles effectively. The base practices that address this purpose are:

> Identify common training needs across the organization based on organizational and project inputs to build the knowledge and skills of the staff.
>
> Develop or acquire training that addresses the common training needs.
>
> Train personnel to have the knowledge and skills needed to perform their roles.
>
> Maintain appropriate records of training and experience for the staff.

Source: *SPICE BPG Version 1.00*, September 1994.

C.3 Malcolm Baldrige National Quality Award Criteria - Employee Education and Training

Areas to Address:

> "- how the company determines needs for the types and amounts of quality and related education and training for all employees, taking into account their differing needs. Include: (1) linkage to short- and long-term plans, including company-wide access to skills in problem solving, waste reduction, and process simplification; (2) growth and career opportunities for employees; and (3) how employees' input is sought and used in the needs determination
>
> - how quality and related education and training are delivered and reinforced. Include: (1) description of education and training delivery for all categories of employees; (2) on-the-job application of knowledge and skills; and (3) quality-related orientation for new employees
>
> - how the company evaluates and improves its quality and related education and training. Include how the evaluation supports improved needs determination, taking into account: (1) relating on-the-job performance improvement to key quality and operational performance improvement targets and results; and (2) growth and progression of all categories and types of employees
>
> - trends in key measures and/or indicators of the effectiveness and extent of quality and related education and training."

Notes:

"Quality and related education and training address the knowledge and skills employees need to meet their objectives as part of the company's quality and operational performance improvement. This might include quality awareness, leadership, project management, communications, teamwork, problem solving, interpreting and using data, meeting customer requirements, process analysis, process simplification, waste reduction, cycle time reduction, error-proofing, and other training that affects employee effectiveness, efficiency, and safety. In many cases, this might include job enrichment skills and job rotation that enhance employees' career opportunities. It might also include basic skills such as reading, writing, language, arithmetic, and basic mathematics that are needed for quality and operational performance improvement.

Education and training delivery might occur inside or outside the company and involve on-the-job or classroom delivery.

The overall evaluation might compare the relative effectiveness of structured on-the-job training with classroom methods. It might also address how to best balance on-the-job training and classroom methods.

Trend results should be segmented by category of employee (including new employees), as appropriate. Major types of training and education should be noted."

Source: *Malcolm Baldrige National Quality Award - 1994 Award Criteria.*

C.4 People Management Capability Maturity Model

Several key process areas of this model are concerned with education and training:

Training and Career Development: Continuously motivate the staff to improve existing knowledge and skills and develop new capabilities that enhance their contribution to the organization.

Knowledge and Skills Analysis: Develop the basic data about tasks performed within the organization's business and the knowledge and skills they require.

Competency Development: Constantly enhance the capability of the staff to perform their business tasks and roles.

Competency-based Practices: Ensure that all people management practices are based in part on the knowledge and skills of staff members.

Source: Curtis, B.; Hefley, W.; Miller, S.; Konrad, M. *People Management Capability Maturity Model, Draft Version 0.2.* Pittsburgh, Pa.: Software Engineering Institute, Carnegie Mellon University, November 1994.

C.5 Statistical Control and Training

Objective: to know when training has been effective, when to stop training, when to start training in a different area

> Use of control charts of employee performance to evaluate training effects on performance

Source: Deming, W. Edwards. *Out of the Crisis.* Cambridge, Mass: Massachusetts Institute of Technology, Center for Advanced Engineering Study, 1982.

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This report provides a high-level topical overview of what can be taught or learned about process improvement. The subject matter is presented within a general framework of six major topic areas, which are described and divided into annotated subtopics. The relationships and application of the subject areas are explained in the context of process improvement activities. Topic areas range from process and process improvement concepts to tools, techniques, teamwork, and interpersonal skills.

The purpose of this report is to assist software engineering educators and trainers in selecting topics for curricula or training programs. It may also be used to guide self-study in this area. Pointers to

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ABSTRACT — continued from page one, block 19

detailed sources of information are given, but no in-depth information is otherwise provided for the topic areas. Consequently, this report is not suitable for use by itself as a means of learning the details of how to do process improvement.