Software Engineering Institute

An Analysis of SEI Software Process Assessment Results 1987-1991

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Review and Approval

This report has been reviewed and is approved for publication.

FOR THE COMMANDER

John S. Herman, Capt, USAF
SEI Joint Program Office

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An Analysis of SEI Software Process Assessment Results: 1987-1991

Abstract: This report focuses on the results of SEI software process assessments conducted over a four-year period beginning in 1987. It characterizes the software processes used by software managers and practitioners at the assessed sites and classifies issues identified during the assessments. The basis for the characterization and classification is a software process maturity model developed by the SEI. This report contributes to the existing body of knowledge on the state of practice of software engineering in the United States by characterizing the sites from a software process maturity perspective and profiling site software process weaknesses. The data analyzed are drawn from SEI software process assessments of 59 government and industry software sites. This work is an analysis of existing assessment data rather than a designed study. The participating sites were not randomly selected; accordingly, they do not necessarily constitute a statistically valid sampling of the U.S. software industry.

1 Overview

1.1 Scope and Objectives

This report focuses on the state of practice of software engineering from a software process perspective. It characterizes the software processes used by software managers and practitioners using a five-level process maturity model developed at the SEI, and classifies process issues identified during SEI assessments conducted at 59 government and industry software sites. The scope of this report does not explicitly consider other important determinants of software supplier performance such as human resource management, automation, business strategy and practices.

A commitment to improve key software processes on a continuing basis is rapidly becoming a high priority for many U.S. software organizations. Among the reasons for this are:

1. Process capability is being increasingly recognized (across many industries) as a key determinant of performance and a source of competitive advantage,
2. Software suppliers (both government and industry) are subject to intensifying competitive pressures, and
3. Software purchasers are becoming increasingly sophisticated and demanding.

Of particular importance to the U.S. Department of Defense (DoD) software community is the increasing use by the DoD of SEI-developed methods such as software capability evaluation for identifying capable contractors during the acquisition phase and for monitoring the results of process improvement programs during contract performance.

The objective of this report is to provide a baseline characterization of the state of software process maturity for a group of 59 U.S. government and industry software sites. A clear understanding of current software process strengths and weaknesses is an important initial step towards formulating plans to improve them in an orderly, progressive and sustainable way.

1.2 Basis for Analysis and Relation to Previous Work

This report is based on data obtained from 59 SEI assessments conducted over a 50 month period beginning in 1987. Collectively, these assessments closely examined 296 software projects and involved approximately 2,500 software managers and practitioners in discussions of software process-related issues in their organizations. Just over half of the sites assessed are industrial organizations working under contract to the DoD; the remainder are commercial and government software organizations.

This work constitutes an analysis and review of available data (resulting from the conduct of SEI assessments), as opposed to a designed study. One of the key characteristics of a designed study is the advance identification of a set of hypotheses to be tested, along with criteria by which the appropriate tests can be constructed and carried out. In contrast, assessments primarily assist organizations in identifying key process-related improvement needs and taking appropriate corrective actions. Consequently, while we believe that the information presented is significant, there are limits to what we can expect to learn or infer from this data.

In conducting the analysis and formulating our conclusions, information of three types was considered:

- Project manager responses to the maturity questionnaire [Humphrey 87] and a demographic data collection form.
- Assessment findings and maturity level ratings determined by the teams conducting the assessments. The participating sites provided the SEI with either the full final assessment report or the findings briefing.
- The collective knowledge and experience that the SEI has acquired as a result of its involvement in the development and application of the software process maturity model.

The analysis consisted of characterizing the projects and sites through selected demographics, software process maturity profiles, and frequency distributions of key process deficiencies identified by the assessment teams.

This report updates and refines an earlier SEI review of assessment data [Humphrey 89b]. The most significant ways in which this report differs from its predecessor are:

- This review is based on a larger set of SEI assessment results (59 sites versus 10 sites and 296 projects versus 55 projects).
- The use of selected demographics to characterize the participating sites.
- The use of a site-based software process maturity profile (previous maturity profiles have been project-based).
- The inclusion of an analysis of assessment findings which shows the frequency with which key process deficiencies were identified by assessment teams.

Because this report is based on an analysis of data which includes most of the SEI-assisted assessment data considered in Humphrey, Kitson, and Kasse's *The State of Software Engineering Practice* [Humphrey 89b], it would be inappropriate to view the two reports as describing distinct snapshots of the state of practice in 1989 and 1991 respectively. Rather, we view this report as a refinement and extension of Humphrey, Kitson, and Kasse's report, based on a larger set of assessment results and the introduction of additional analyses.

This report is organized into 4 sections. Sections 1 and 2 provide background and context for the analysis of assessment results. Section 3 describes the data collected, characterizes the projects and sites which participated, and describes the software process maturity status of the participating sites. Section 4 presents an analysis of key process weaknesses identified by the assessments.

1.3 Summary of Main Points

The analysis of data collected from the participating sites shows that most of the software work being performed is conducted at the initial level of process maturity. While it is undoubtedly true that some good results are being achieved, it is also true that continuing to operate at low levels of process maturity (levels 1 and 2) is a risk for software supplier organizations in the face of an increasingly competitive industry, increasingly sophisticated and demanding customers, and rising complexity of systems being attempted. Similarly, these results suggest improvement opportunities for organizations searching for ways to become increasingly effective and efficient.

On average, site assessments identified 7.6 findings and 9.3 KPA findings. Because of this, site findings usually span at least two maturity levels.

The five most frequently occurring findings areas are product engineering, project planning, organization process definition, project tracking and oversight, and training program.[1]

The five least frequently occurring findings areas are process change management, defect prevention, subcontract management, quality management, and peer reviews.

[1] The findings areas used are drawn from the SEI's Capability Maturity Model for Software V1.0. See Appendix B for additional details.

2 Background and Context

2.1 SEI Focus on Process

The Software Engineering Institute (SEI) was established by the DoD in 1984 to provide leadership in advancing the state of the practice of software engineering to improve the quality of systems that depend on software. Since early 1987 the SEI has focused on software process as a principle means of accelerating the maturity of software engineering as a practice and facilitating the effective introduction of available technology. This focus is based on the premises that the process of producing and evolving software products can be defined, managed, measured, and progressively improved, and that the quality of a software product is largely governed by the quality of the process used to create and evolve it.

The SEI approach has emphasized the following:

1. Developing and evolving a software process maturity model,
2. Developing and transitioning an evaluation method for DoD software acquisition agencies and their prime contractors,
3. Developing and transitioning a companion assessment method for use by software suppliers in assessing their software engineering capabilities and determine improvement needs and priorities, and
4. Periodically publishing reports summarizing the results of SEI assessments.

2.2 Software Process Management Overview

The *software process* is the set of activities, methods, and practices that guide people in the production of software. An effective process must consider the relationships of the required tasks, the tools and methods, and the developers' skills, training, and motivation.

Software process management is the application of process engineering concepts, techniques, and practices to explicitly monitor, control, and improve the software process. It is only one of several activities that must be effectively performed for software-producing organizations to be consistently successful. Capable and motivated technical people are critical; knowledge of the ultimate application environment is needed, as is detailed understanding of the end user's needs [Curtis 88]. Even with all these capabilities, however, inattention to software management problems will likely result in disappointing organizational performance. A more comprehensive discussion of the role and significance of software process, the discipline of software process management, and software process improvement methods is provided in Humphrey's *Managing the Software Process* [Humphrey 89a] and Kitson and Humphrey's *The Role of Assessment in Software Process Improvement* [Kitson 89].

This view of process and process management has led to the development of a process maturity model (described in Section 2.3), a related software process maturity questionnaire [Humphrey 87], and a software process assessment method (described in Section 2.4). These form key elements of SEI's software process improvement framework.

2.3 SEI Software Process Maturity Model

The extent to which a software organization has adopted and institutionalized a continuous improvement focus can be characterized with the aid of the software process maturity model shown in Figure 2-1. This five-level model identifies the key improvements required at each level and establishes a priority order for moving to higher levels of process maturity.

Level	Characteristic	Key Challenges	Result
5 Optimizing	Improvement fed back into process	Human intensive process Maintain organization at optimizing level	Productivity & Quality
4 Managed	(Quantitative) Measured process	Changing technology Problem analysis Problem prevention	
3 Defined	(Qualitative) Process defined and institutionalized	Process measurement Process analysis Quantitative quality plans	
2 Repeatable	(Intuitive) Process dependent on individuals	Training Technical practices Process focus	
1 Initial	(Ad hoc / chaotic)	Project management Project planning Configuration management SQA	Risk

Figure 2-1 SEI Software Process Maturity Model

At the Initial level (level 1), an organization can be characterized as having an ad hoc, or possibly chaotic process. Typically, the organization operates without formalized procedures, cost estimates, and project plans. Even if formal project control procedures exist, there are no management mechanisms to ensure that they are followed. Tools are not well integrated with the process, nor are they uniformly applied. In addition, change control is lax, software quality assurance (if present at all) is ineffective, and senior management is not exposed to or does not understand the key software problems and issues. When projects do succeed, it is generally due to the heroic efforts of a dedicated team rather than to the process capabilities of the organization.

An organization at the Repeatable level (level 2) has established basic project controls such as project management, management oversight, quality assurance, and change control. The strength of the organization stems from its experience at doing similar work, but it faces major risks when presented with new challenges. The organization has frequent quality problems and lacks an orderly framework for improvement.

At the Defined level (level 3), the organization has laid the foundation for examining the process and deciding how to improve it. A group has been established to focus and lead the process improvement efforts, to keep management informed on the status of these efforts, and to facilitate the introduction of a family of software engineering methods and technologies. Such groups are typically known as Software Engineering Process Groups, or SEPGs.

The Managed level (level 4) builds on the foundation established at the defined level. When the process is defined, it can be examined and improved but there is little data to indicate effectiveness. Thus, an organization at this level has established a minimum set of measurements for the quality and productivity parameters of each key task. The organization has also established a process database with resources to manage and maintain it, to analyze the data, and to advise project members on its meaning and use.

Two requirements are fundamental to advance from the Managed to the Optimizing level (level 5). Data gathering should be automated, and management should redirect its focus from the product to process analysis and improvement. At the optimizing level, the organization has the means to identify the weakest process elements and strengthen them, data are available to justify applying technology to various critical tasks, and numerical evidence is available on the effectiveness with which the process has been applied. The key additional activity at the optimizing level is rigorous defect cause analysis and defect prevention.

These maturity levels have been selected because they do the following:

- Reasonably represent the historical phases of evolutionary improvement of actual software organizations.
- Represent a measure of improvement that is reasonable to achieve from the prior level.
- Suggest interim improvement goals and progress measures.
- Make obvious a set of immediate improvement priorities, once an organization's status in this framework is known.

While there are many aspects to the transition from one maturity level to another, the basic objective is to achieve a controlled and measured process as the foundation for continuous improvement.

It has been our experience that when software organizations are assessed against this maturity framework, the assessment method enables reasonably accurate placement of them on the maturity scale and helps to identify key improvement needs. In practice we find that when management focuses on the few highest priority items, their organizations generally make rapid improvement in being able to produce quality software products on time and within budget. While the use of tools and technology can enhance software engineering capability, such investments are generally of limited value for organizations with low-maturity software processes.

Humphrey and Kitson provide more comprehensive descriptions of software process management and the maturity model ([Humphrey 89a], [Kitson 89]). It should be noted that the SEI has published two technical reports which provide an elaboration and refinement of the maturity model discussed above ([Paulk 91], [Weber 91]), referred to as the SEI Capability Maturity Model for Software (CMM).

2.4 Assessing Software Organizations

There are a number of ways the software process maturity model can be applied. The SEI has developed and applied:

- SEI-assisted assessments
- self-assessments
- assessment tutorials
- SEI-licensed vendor assessments
- capability evaluations

While all these methods have contributed to the SEI's base of knowledge and understanding of the software process, the data in this report was obtained solely from SEI-assisted assessments and self-assessments.[1] These methods are described in Sections 2.4.1 and 2.4.2, respectively. A more comprehensive discussion of the principles of software process management, the role of assessment in software process improvement, and how assessments are conducted can be found in Kitson and Humphrey [Kitson 89].

2.4.1 SEI-Assisted Assessments

An SEI-assisted assessment is an appraisal of a site's current software process by a trained team of experienced software professionals. Typically, a team is composed of four to six SEI professionals and one to three professionals from the organization being assessed. The method for conducting such assessments has been developed by the SEI [Olson 89]. The assessment team receives SEI training prior to conducting the assessment. The goal is to facilitate improvement of the organization's software process. Typically, four to six projects are examined during an assessment. The assessment team identifies the most important software process issues currently facing the organization and formulates recommendations to deal with them.

SEI-assisted assessments are conducted in accordance with an assessment agreement signed by the SEI and the organization being assessed. This agreement provides for senior management involvement, organizational representation on the assessment team, confidentiality of results, and follow-up actions.

[1]There was limited vendor assessment data available at the time the analysis for this report was performed; capability evaluations, as defined by the SEI, do not produce findings or a site maturity rating; assessment tutorials do not produce findings or a site maturity rating.

The SEI has conducted SEI-assisted assessments since February 1987 and uses the information gained to refine and improve the assessment method and to add to its assessment database.

2.4.2 Self-Assessments

Self-assessments are SEI assessments conducted with little or no direct SEI involvement. Self-assessment teams are composed primarily of software professionals from the organization being assessed, with possibly one or two SEI assessment coaches present. The context, objective, and degree of validation are the same as for SEI-assisted assessments. Organizations which have received SEI self-assessment training agree to provide the SEI with the results of their assessments. These results are added to SEI's assessment database.

3 Selected Demographics and Site Maturity Level Profile

3.1 Overview of Participating Organizations and Sites

To minimize confusion we shall henceforth use the term site to refer to that subset of an organization which was the focus of the assessment. In general, a site was one part of a larger corporate entity. In some cases, the organizations were very large (e.g., U.S. Air Force, Unisys) and had two or more sites which contributed assessment results to the SEI.

The data for this report is taken from SEI assessments of 59 sites during the period February 1987 through March 1991.[1] Figure 3-1 shows a breakout of how the sites characterized themselves according to site type.

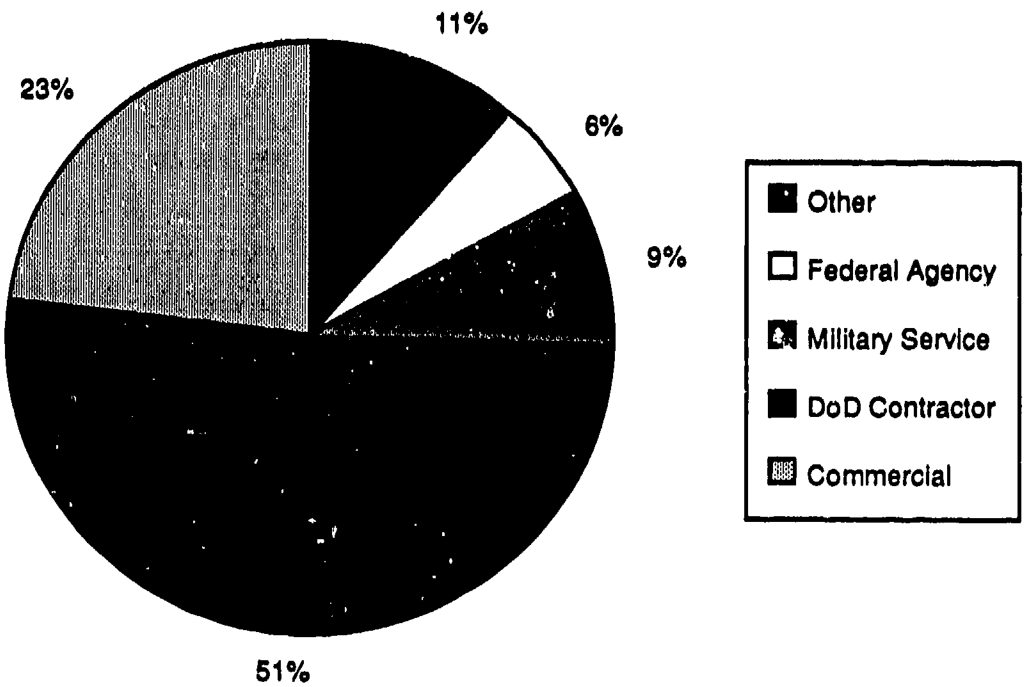

Figure 3-1 Participating Site Types

[1]Demographic data was not available for the complete set of 59 site assessments and 296 projects; we received demographic data from 36 sites covering 170 projects.

Appendix A lists the twenty-seven participating organizations. Nineteen of the twenty participating industrial organizations were ranked among the top one hundred prime DoD contractors for fiscal year 1990 based on net contract value, ten were among the top twenty, and sixteen were among the top fifty [Carroll 91]. Collectively, these nineteen organizations were awarded close to forty billion dollars worth of contracts in fiscal year 1990. Appendix A also includes the individual organization rankings for fiscal year 1990 and total contract value awarded.

Figure 3-2 shows how the site assessments considered in this report are distributed over time. In total, we have data from thirteen SEI-assisted assessments and forty-six self-assessments. All assessment teams received training in the SEI assessment method directly from the SEI. Some sites which conducted SEI-assisted assessments in 1987 or 1988 were re-assessed (either by SEI-assisted assessment or self-assessment); the more recent assessment results have been considered in this work. Hence, each site is represented by exactly one set of assessment results. For this reason, the counts of SEI-assisted assessments conducted in 1987 and 1988 do not reflect the actual number of such assessments conducted during those years. (There were actually four conducted in 1987 and six conducted in 1988.)

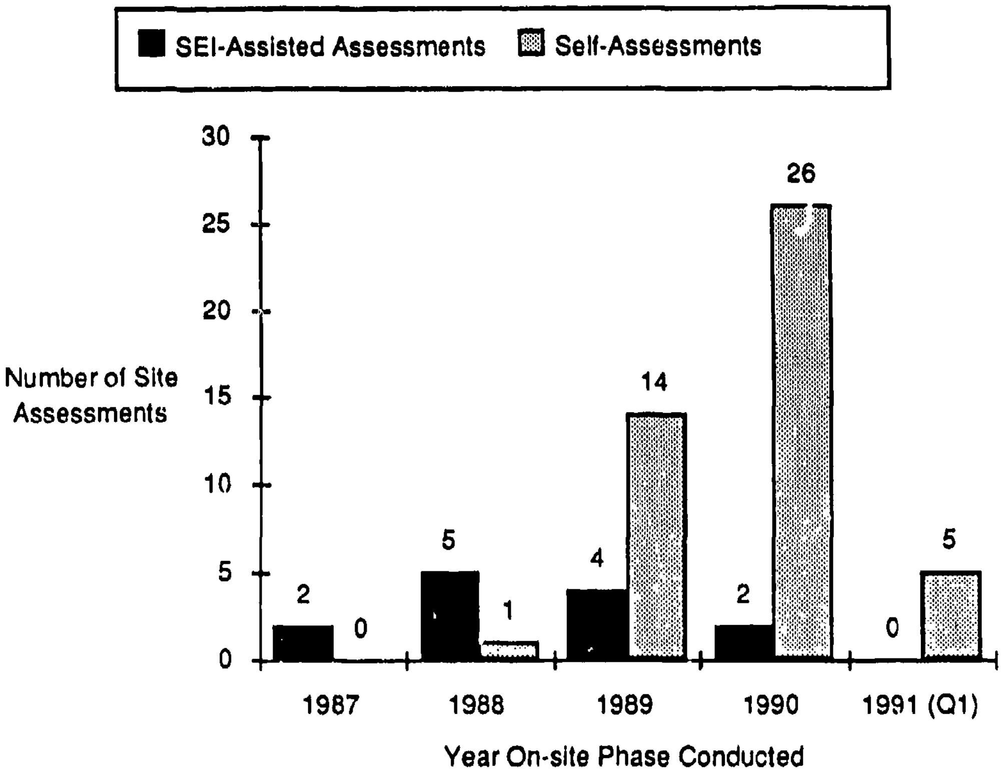

Figure 3-2 Time Distribution of Site Assessments

3.2 Statistical Considerations

This work is an analysis of existing assessment data rather than a designed study. The participating sites were not statistically selected and do not therefore constitute a random sample. Accordingly, we cannot claim that the data presented or the inferences drawn in this report are representative of the entire U.S. software industry.

3.3 Selected Project Demographics

To characterize the set of projects selected for the focus of each site assessment the following views of the available demographic data have been prepared: the lifecycle phase of the project, the product size in thousands of source lines of code (KSLOC), and the peak project staffing. The demographic data was provided by the site project managers who responded to the maturity questionnaire for their projects.

The first chart, Figure 3-3, shows the lifecycle phase of the project at the time of the assessment. Since an assessment focuses on how the software work is actually conducted (as opposed to how it was planned or how it should have been done), current lifecycle phase was one of the project selection considerations. In general, projects which had progressed beyond the requirements analysis phase were considered more desirable candidates for inclusion in the scope of the assessment. Because of the lifecycle categories used, we can also differentiate between "new development" (requirements analysis or development and test phases) and "maintenance" (production and deployment phase) projects. As Figure 3-3 shows, the majority of projects (68%) were new development, and about 1 in 5 were maintenance.

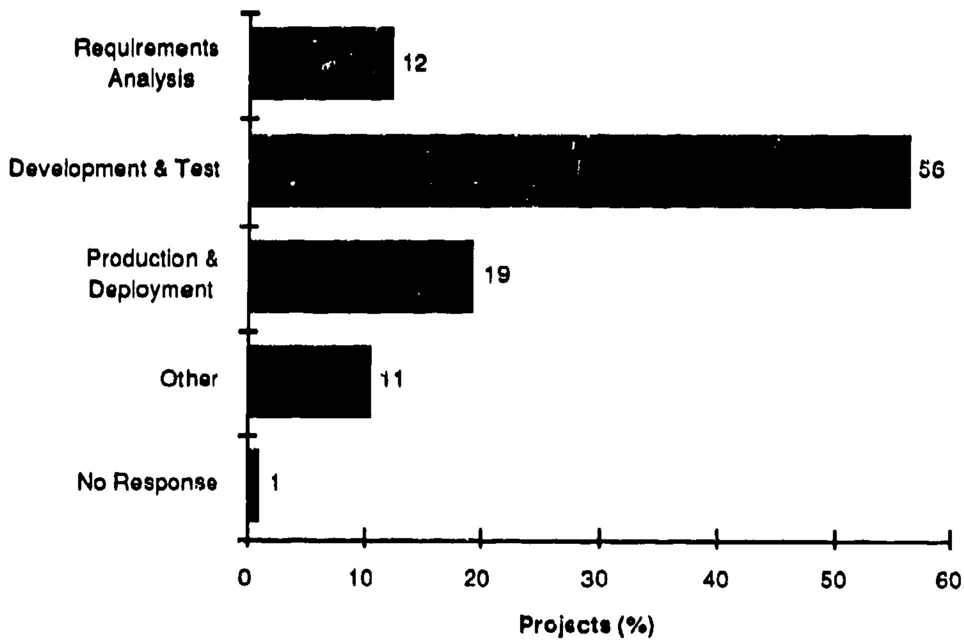

Figure 3-3 Project Life-Cycle Phase Profile

Figure 3-4 shows a product size profile for the projects. The projects are roughly evenly divided among the size categories of small, medium and large, with small projects (<100 KSLOC) being the largest single category. Very large projects were a small percentage (9%) of the total group.

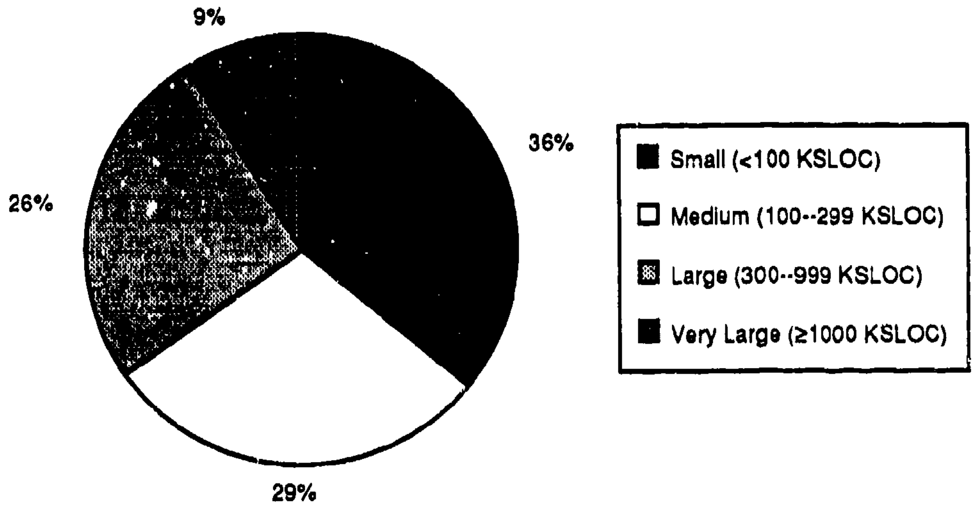

Figure 3-4 Product Size Profile

Figure 3-5 shows the peak project staffing profile for the projects. In some cases this was actual, and in others it was projected, depending on where the project was in its lifecycle. Note that 34% of the projects included in assessments have been been staffed by teams of

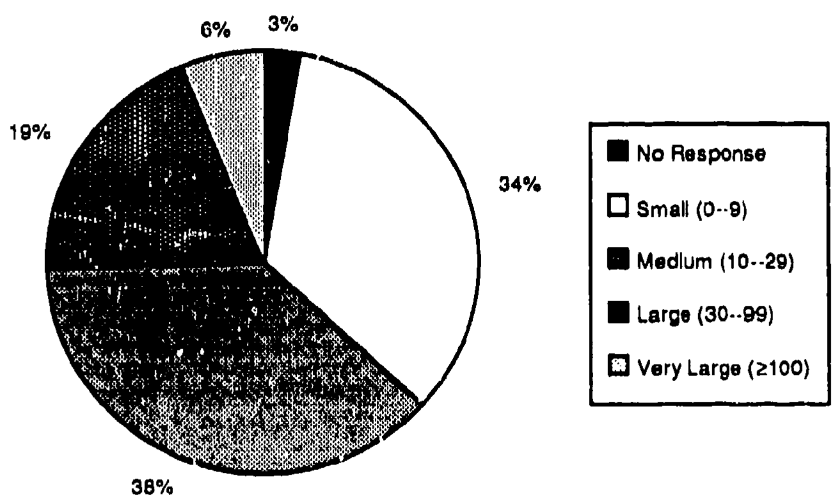

Figure 3-5 Peak Project Staffing Profile

fewer than ten people. This is consistent with our observation that although the way in which process management principles are implemented varies by project (and site) size, there is little disagreement concerning the fundamental applicability of process management principles and concepts independent of size.

3.4 Site Software Process Maturity Profile

The software process maturity level measures the extent to which a site has institutionalized continuous process improvement in its key software processes. Figure 3-6 displays the profile of software process maturity for the 59 participating sites as reported by the teams conducting the assessments.

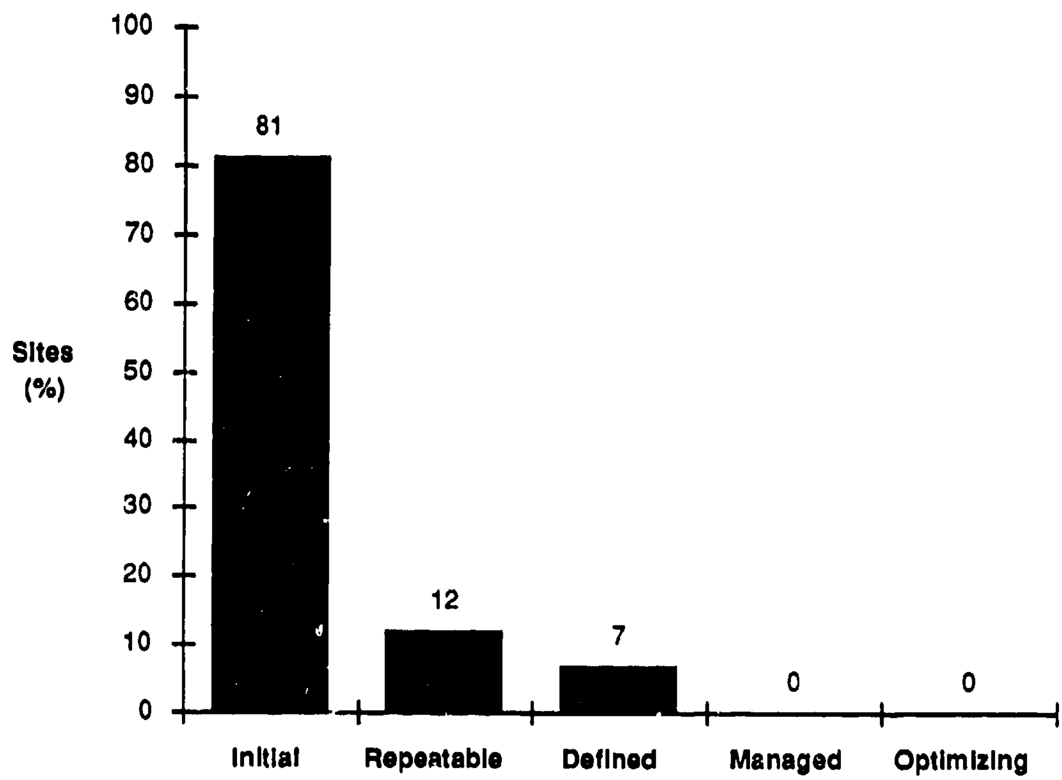

Figure 3-6 Site Software Process Maturity Profile

As is apparent from the chart, none of the participating software sites were performing at the Managed level (level 4) or the Optimizing level (level 5) at the time their assessments were conducted.

Figure 3-6 is based upon results from two kinds of assessments: SEI-assisted assessments and self-assessments. Figure 3-7 shows the maturity profile broken out by assessment type. The sites which conducted SEI-assisted assessments show a more favorable profile in comparison to sites which conducted self-assessments. The most significant factor accounting for these differences is the selection criteria which were employed by the SEI in selecting candidate organizations for SEI-assisted assessments. Organizations receiving SEI-assisted assessments were limited to those considered to be doing advanced software work and/or those organizations which were of particular importance to the DoD.

An important related point is that the profile shown in Figure 3-6 represents the general state of practice (of the group of participating sites) from a software process maturity perspective as opposed to the leading edge of practice. Currently, the SEI-assisted assessment portion of Figure 3-7 is the closest approximation we have to the latter.

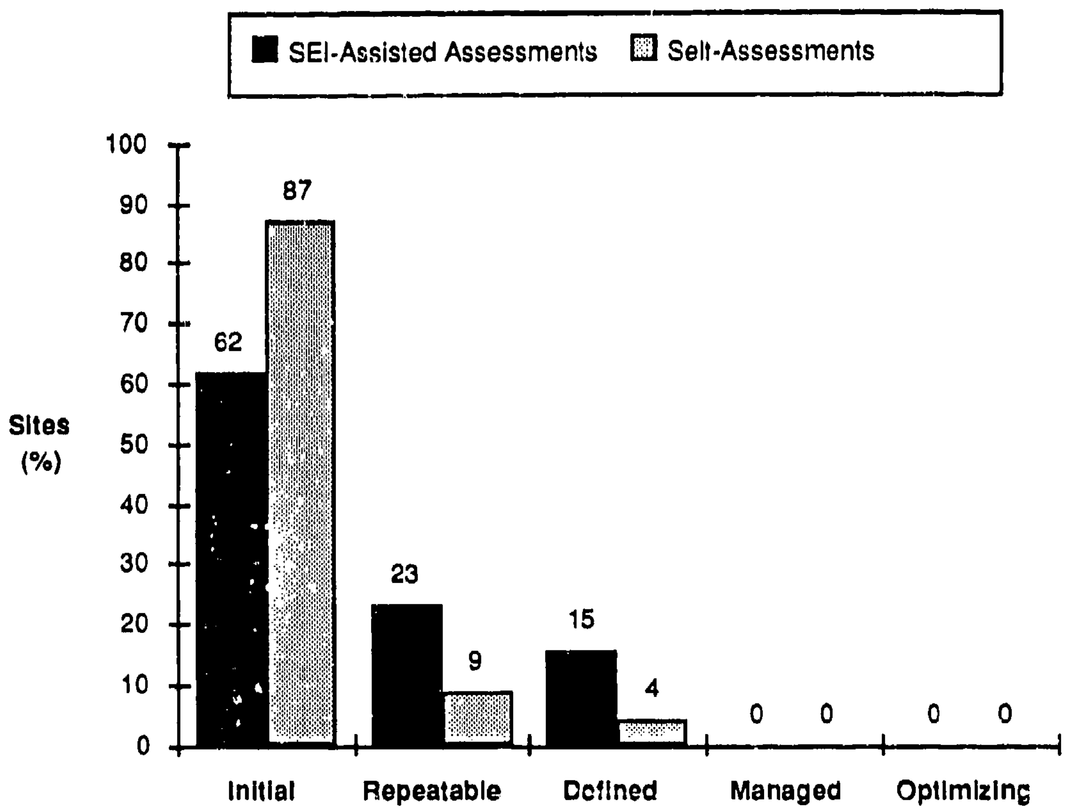

Figure 3-7 Site Software Process Maturity Profile Breakout By Assessment Type[1]

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[1]Thirteen sites encompassing 63 projects conducted SEI-assisted assessments; 46 sites encompassing 233 projects conducted self-assessments.

4 Assessment Findings Analysis

Section 3 focused on selected project and site demographics and the process maturity status of the participating sites. This section provides more visibility into the specific process issues (i.e., findings) identified by the assessment teams during assessments of the 59 participating sites by analyzing them from the perspective of the SEI's Capability Maturity Model for Software V1.0 (CMM).

4.1 Rationale for Findings Focus and Overall Approach

The primary objective of the assessment findings analysis is to provide greater visibility into the specific types of process-related issues identified during assessments of the participating sites.

By definition, findings are the key process-related weaknesses which the site needs to focus on next as it strives to institutionalize continuous process improvement (i.e., a continuous advance to higher levels of process maturity).

A sample finding (extracted from the briefing conducted at the conclusion of an assessment) relating to the area of project estimation could be:

- Lack of wide-spread use of formal procedures and tools for estimating software size, cost, and schedule, and
- Limited and inconsistent data collection and dissemination to support estimation

Figure 4-1 illustrates how findings are derived (from an information flow perspective) during the course of an SEI assessment. This graphic shows how findings are the result of the assessment team's consideration of a considerable amount of information about site software practices and procedures in the context of the software process maturity model, the specific circumstances of the site, and the team's collective experience and judgement.

As a consequence, the findings constitute a relatively robust and stable focal point for analysis, in contrast to project manager responses to the maturity questionnaire or the results of discussions with practitioners alone. In addition, we have a high level of confidence in the accuracy and validity of the findings because they were formulated in the context of information about the real issues confronting managers and practitioners on a daily basis, and were developed in the context of the SEI assessment method, a structured diagnostic method. For these reasons, we have chosen to focus on the findings as an important source of additional information on the specific issues faced by software supplier organizations.

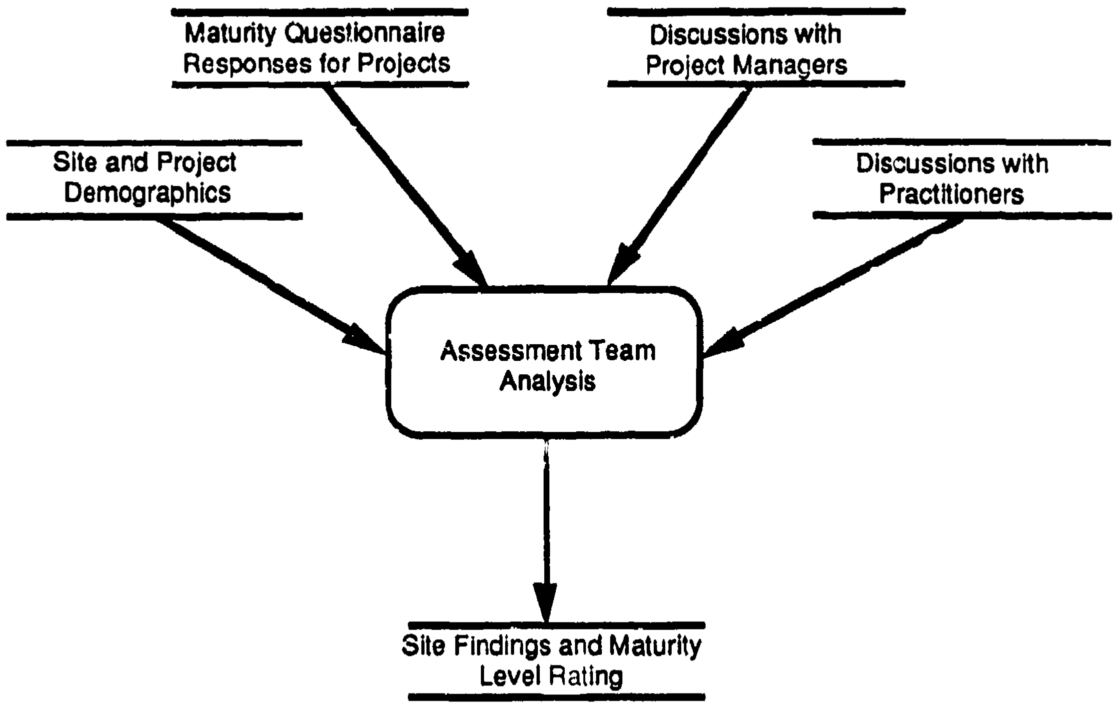

Figure 4-1 Assessment Findings Data Flow

The CMM was chosen as the framework for the analysis of findings because it constitutes the future basis for the SEI assessment method (and other process-related SEI products and services) and constitutes a relatively well-defined and complete set of key process areas (KPAs). Appendix B provides a brief overview of some of the key CMM-related concepts and terms as well as indications of where additional CMM information can be found.

The initial step in the analysis of assessment findings was to decompose each finding into KPAs. As used in this analysis, the KPAs can be seen as a set of coordinates (or dimensions) in *process space.* In the same way that any point in a plane can be characterized by knowing its coordinates with respect to a particular coordinate system, we mapped findings into KPA process space using the CMM KPA coordinate systems. For example, the finding presented at the beginning of this section maps into the project planning and organizational process focus KPAs. The motivation for performing this classification was to convert the findings into common or neutral terms which would facilitate comparison and analysis. In addition, framing them in terms of the CMM KPA categories provides a bridge from the current set of assessment data to the "next generation" of assessment data resulting from the conduct of CMM-based SEI assessments.

4.2 Analysis Method and Examples

Two important aspects of an SEI assessment are the preparation and delivery of a findings briefing to the site senior management team and participating personnel, and the preparation and delivery of a comprehensive final written report. The text from final findings briefings, and sometimes final reports, was used as the basis for this analysis. Each major issue area identified during an assessment was treated as one finding. In general, each such finding discussed one or more related areas of concern.

Each finding was reviewed and then associated with appropriate KPAs. In determining the relevant KPAs for a given finding, we used the fundamental criteria that one or more KPAs were relevant if their presence (or satisfaction) would have made it unlikely for an assessment team to have generated the finding. For example, the finding presented in Section 4.1 would not have been generated if the project planning and organizational process focus KPAs were fully in place at the site. The determination of relevancy required the review and consideration of the specifications of the KPAs contained in Weber, Paulk, Wise, and Withey's *Key Practices of the Capability Maturity Model* [Weber 91].

There were instances in which a finding or parts of a finding related to issues which are not within the current scope of the CMM. In these cases, the issue was assigned to the catch-all "Other" category. Multiple instances of the same KPA within a set of site assessment findings were counted as one occurrence; thus, the highest possible frequency for a given KPA for a site assessment is one.

For example, the following finding was mapped to the software configuration management KPA:

Configuration management not consistently applied
- throughout the software development life cycle
- across organizations/projects
- for system maintenance and support
- to vendor supplied software

The following finding was was determined to have significant overlap with three KPAs—project planning, project tracking and oversight, and other:

Ineffective commitment process
- initial estimates become firm commitments
- commitment made without adequate technical participation
- little opportunity to renegotiate commitments
- over-emphasis on achieving commitments at the expense of everything else
- minimal client acceptance of the methodology
- insufficient participation in reviews

This mapping of findings to KPAs resulted in a set of KPA weaknesses for each site. This data was then used to construct frequency distributions of KPAs which are the subject of the next section.

4.3 CMM Classification Results

4.3.1 KPA Incidence Distribution by Composite KPA Maturity Level

Figure 4-2 shows the distribution of KPAs for all 59 sites by composite KPA maturity level. The individual KPAs are not shown in this view of the data. Since this chart is based on the total number of KPA findings (547 of them), it is apparent that the bulk of the issues considered most important by the assessment teams are level 2 and level 3 issues. This is consistent with our expectations based on the maturity level profile presented in Figure 3-6, which showed 93% of the sites to be at level 1 or 2 and therefore facing level 2 and 3 KPA issues. Figure 4-2 shows 85% of the KPA findings to be in the level 2 or 3 categories. In Section 4.4.1, we will present additional information which helps us better understand why an apparently disproportionate number of findings are at level 3 instead of level 2.[1]

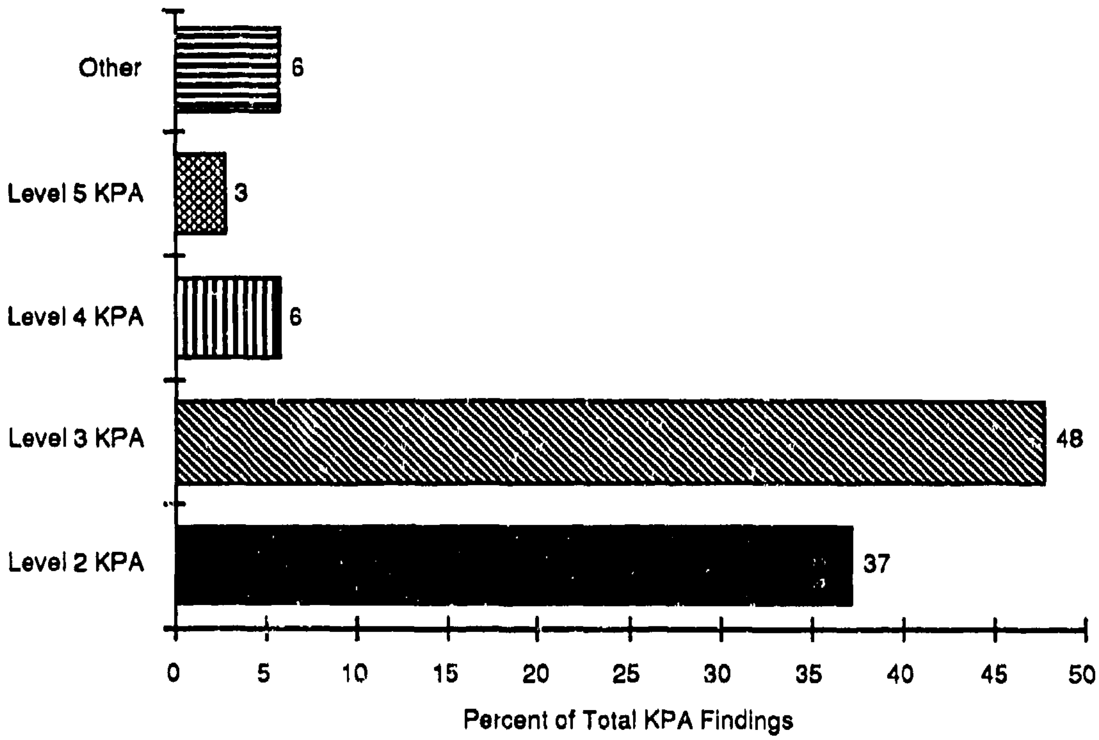

Figure 4-2 KPA Incidence Distribution by Composite KPA Maturity Level[2]

4.3.2 Individual KPA Incidence Distribution

Figure 4-3 shows the frequency distribution of individual KPAs across all 59 sites with the KPA categories presented in maturity level order (level 2 KPAs are the bottom, then level 3 KPAs and so on). Note that this chart shows the percentage of sites which had KPA findings in the various categories shown.

The following general observations can be made from this view of the data:

- The five most frequently occurring KPA findings were
  - product engineering (93%)

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[1] Figure 3-6 shows 81% of the sites to be at maturity level 1 and 12% at level 2.

[2] Note that the bar patterns used in this figure are primarily for helping to make Figure 4-3 more readable; the patterns are carried over into that figure from this one.

- project planning (86%)
- organization process definition (76%)
- project tracking and oversight (75%)
- training program (73%)

- The five least frequently occurring KPA findings were
  - process change management (0%)
  - defect prevention (3%)
  - subcontract management (8%)
  - quality management (14%)
  - peer reviews (22%)
- In general, our expectation that level 4 and level 5 KPAs would have a low incidence rate is confirmed; however the incidence of process measurement and analysis (41%) and technology innovation (24%) is relatively high.
- Given the high percentage of level 1 sites (81%), subcontract management (a level 2 KPA) does not appear to be a significant problem area for these sites (with an incidence of only 8%).
- Similarly, the incidence level of peer reviews (22%) is lower than would be expected given the number of sites assessed to be at levels 1 and 2.
- Just over half of the sites were considered (by the assessment team) to be facing important issues which fall outside the current scope of the CMM ("Other" category - 56%). Examples of such issues include organizational structure and failure of previous management initiatives.

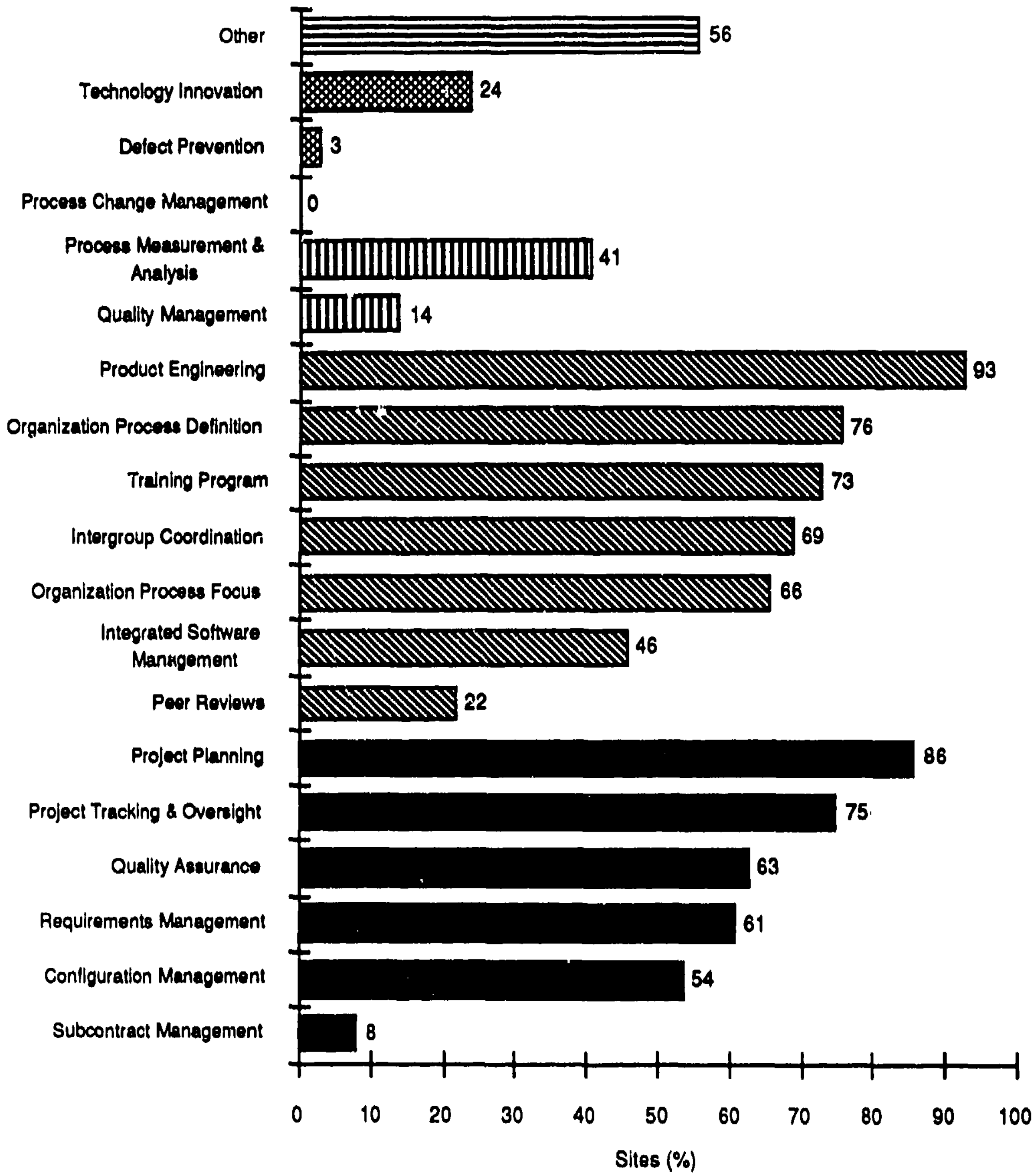

Figure 4-3 Individual KPA Distribution

4.4 Understanding and Interpreting the KPA Distributions

There are a number of factors to consider when interpreting and understanding the KPA distributions presented above. In this section we will explain how limiting the number of assessment findings, along with the KPA structure of the CMM, impacts the KPA distributions presented previously. Then we will present rationale for some of the observations made about the individual KPA distributions. Finally, we will introduce additional considerations believed to have an impact as well as identifying other factors which might be significant.

4.4.1 Effect of Number of Findings/KPAs Identified on Assessments

Assessment teams are trained to limit the number of findings to a manageable level (5-9 is the range suggested by the SEI) and to prioritize them as per the precedence relation implicit in the maturity model. Sites are then advised to focus their improvement efforts on the highest priority issues first. We would expect these issues for the most part to map to findings related to KPAs at the maturity level one above the sites' current rating.

One of the implications of this guidance is that a site may have findings which map into process areas which are beyond what the site needs to focus on to advance to the next higher maturity level. The "closer" the site currently is to the next higher maturity level, the higher the proportion of findings which address issues related to KPAs at maturity levels two or more above the site's current rating.

For example, we would generally expect that, in the frequency distribution of KPAs for maturity level 1 sites, there will primarily be instances of maturity level 2 process issues, plus some level of incidence of level 3 process issues. Similarly, for the frequency distribution of process issues for maturity level 2 sites, there will primarily be instances of maturity level 3 process issues, plus some level of incidence of level 4 process issues.

Figures 4-4 and 4-5 show the breakdown of findings and KPAs from an occurrence perspective. That is, Figure 4-4 shows the number of assessments that had a specific number of findings. Similarly, Figure 4-5 shows the number of assessments that, as per our mapping from findings to KPAs, had a specific number of KPAs indentified as issue areas.

In general, the results in Figure 4-4 are generally consistent with our expectations that most assessments would yield between five and nine findings — 74% of the assessments fit into this range. The average number of findings per assessment by various groupings is as follows:

- across all sites (59) = 7.6
- level 1 sites (48) = 7.8
- level 2 sites (7) = 7.0
- level 3 sites (4) = 6.5

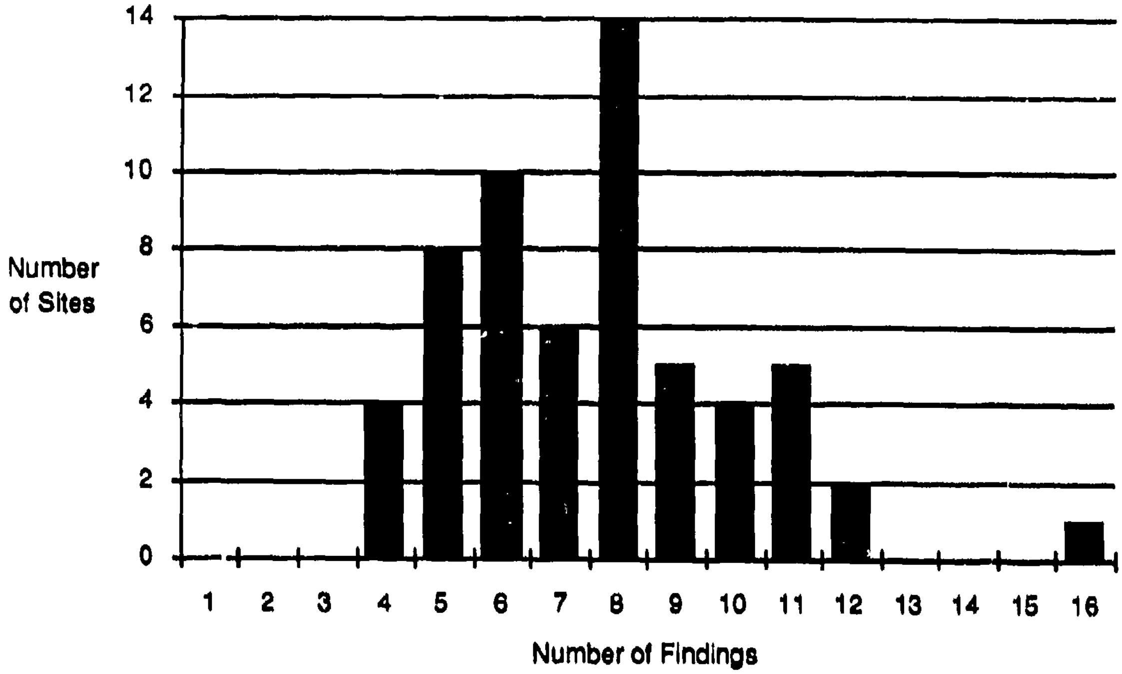

Figure 4-4 Number of Findings Identified on SEI Assessments

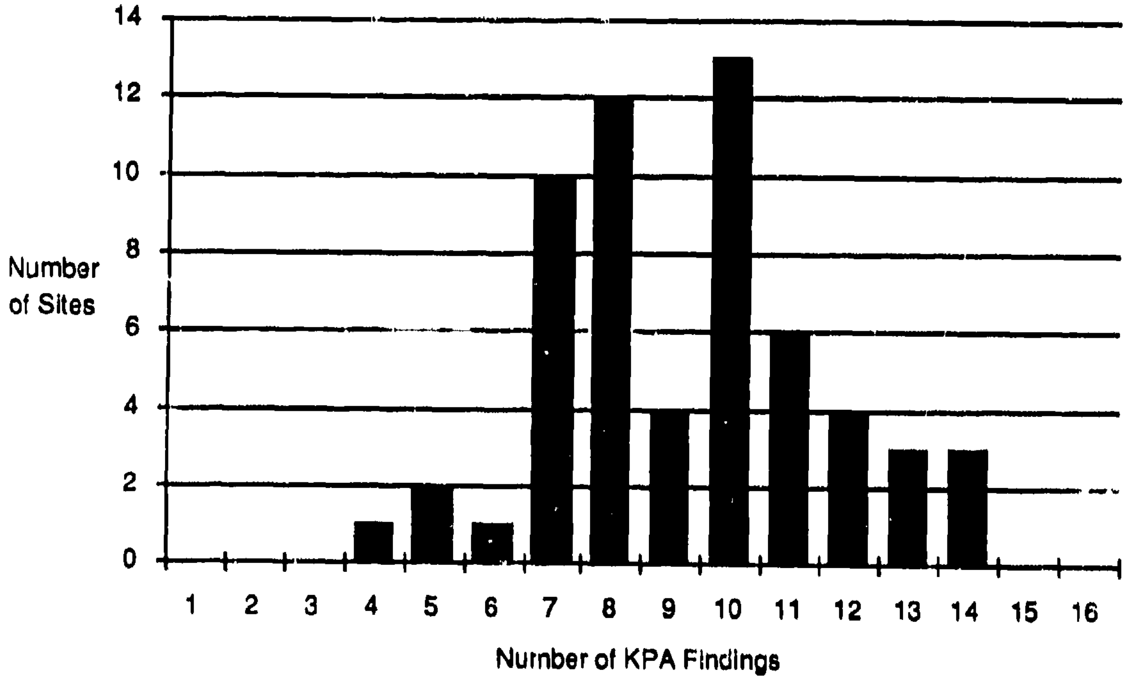

Figure 4-5 Number of KPAs Identified on SEI Assessments

Since the CMM KPA framework was not explicitly utilized in any of the 59 assessments we are considering, there are no a priori expectations about the number of KPAs which would surface as issues during an assessment. Based on the assessment finding-to-KPA space mapping, the average number of KPAs per assessment by various groupings is as follows:

- Across all sites (59) = 9.3
- Level 1 sites (48) = 9.6
- Level 2 sites (7) = 7.7
- Level 3 sites (4) = 8.0

The key point of this analysis, which helps explain the distribution of KPAs shown in Figures 4-2 and 4-3, is that we should expect level 1 sites to have, on average, 3 or 4 KPAs cited as issues which are beyond level 2 (since there are six level 2 KPAs — refer to Figure B-1). In addition, since we expect some level 1 sites to be closer to level 2 than others, we expect that some percentage of the level 1 sites will have more than 3 or 4 KPAs in the level 3 or above category.

We expect the impact of spilling over into the next higher maturity level to be less pronounced for sites rated at maturity level 2 since there are seven KPAs at level 3 and the level 2 sites averaged 7.7 KPAs per assessment.

4.4.2. Other Factors

There have been instances where sites are rated at a particular maturity level in spite of the presence of findings at a lower maturity level. This is typically done when the assessment team feels the site is borderline and decides to give it the benefit of the doubt. For this reason, we expect that the frequency distributions will also show an incidence of process areas at a level lower than that of the site's overall maturity rating.

We also expect to see some anomalous variations deriving from the complexity and difficulty of an assessment plus the inherent variation deriving from its human-intensive nature (e.g., the occurrence of level 4 or 5 process areas at level 1 sites, or some occurrence of level 5 process areas for level 2 sites).

Other factors that might be significant to the KPA profiles include:

- Differences between the original maturity model (Figure 2-1) and the CMM (Figure B-1)
- Current KPA partitioning and/or their maturity level associations
- Our mappings from findings space into KPA space
- Definition of the SEI assessment method
- Extent to which assessment teams followed SEI guidance
- Ability of assessment teams to identify or differentiate findings that are consistent with the site's maturity level
- Assessment team bias for technological solutions

The extent to which these (or other factors) are significant is not well understood at this time.

4.5 Findings Analysis Conclusions

With a few minor exceptions, our qualitative understanding of the findings distribution in KPA space is good. It is, in general terms, consistent with the site maturity level profile.

On average, site assessments identified 7.6 findings and 9.3 KPA findings. Because of this the findings usually span at least two maturity levels.

The five most frequently occurring findings areas are product engineering, project planning, organization process definition, project tracking and oversight, and training programs. The five least frequently occurring findings areas are process change management, defect prevention, subcontract management, quality management, and peer reviews.

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In gathering the material for this report, the authors are deeply indebted to the organizations that provided us with the results of their SEI assessments; this work would not have been possible without their cooperation. Section 2 was taken (with minor changes) from Humphrey, Kitson, and Gale's *A Comparison of U.S. and Japanese Software Process Maturity* [Humphrey 91]. We appreciate the many helpful suggestions provided by our SEI colleagues who reviewed various versions of this material: Edward Averill, John Baumert, Dan Bidwa, Bill Curtis, Ken Dymond, Jim Hart, Watts S. Humphrey, Pete Malpass, Mary Merriil, Mark Paulk, Rich Pethia, and Jane Siegel.

This work is dedicated to the loving memory of Julian Dolso Masters.

Appendix A Participating Organizations

The 27 organizations shown in Table A collectively provided the SEI with results from SEI assessments conducted at one or more of their software sites. Organizational ranking (within the top 100 prime Defense Department contractors for fiscal year 1990 based on net contract value) and total contract value data are taken from Carroll Publishing Company's *DEFENSE Industry Services* [Carroll 91].

Organization Name	Top 100 Ranking	Total Contract Value (K$s)
ALCOA	NA	NA
The Boeing Company	11	2267
Computer Sciences Corporation	53	319
Loral Corporation (Ford Aerospace)	31	618
General Dynamics	2	6306
General Electric Company	3	5589
GTE Corporation	17	1294
Harris Corporation	71	188
Honeywell Inc.	15	1388
General Motors Corporation (Hughes Aircraft Company)	4	4107
IBM Corporation	18	1286
Jet Propulsion Laboratory	NA	NA
LTV Corporation	20	1183
McDonnell Douglas Corporation	1	8211
Philips (Magnavox Electronic Systems Company)	56	297
Medtronic	NA	NA
Motorola Inc.	45	403
Northrop Corporation	26	746
Pacific Bell	NA	NA
Software Productivity Consortium	NA	NA
Texas Instruments Inc.	29	704
TRW Inc.	22	1087
Unisys Corporation	16	1376
US Air Force	NA	NA
US Army	NA	NA
US Navy	NA	NA
Westinghouse Electric Corporation	12	2243
Total Contract Value	NA	39612

Table A Participating Organizations

Appendix B About the CMM

As noted in Section 2, the SEI has released an elaboration and refinement of the SEI process maturity model ([Paulk 91], [Weber 91]), referred to as the SEI Capability Maturity Model for Software V1.0 (CMM). In the CMM, maturity levels 2 through 5 are characterized by a set of key process areas (KPAs) as shown in Figure B-1. In order for a site to be considered to be performing at a given level of maturity, it must be determined that the site has shown a specific level of competency in each of the associated key process areas. For example, if a site was determined to be deficient in the area of software project planning (as specified in Weber, Paulk, Wise, and Witney [Weber 91]), then it would be considered to be performing at the initial level of process maturity.

Maturity Level	Characteristic	Key Process Areas
5 Optimizing	Continuous process capability improvement	Process change management Technology innovation Defect prevention
4 Managed	Product quality planning and tracking of measured software process	Quality management Process measurement and analysis
3 Defined	Software processes defined and institutionalized to provide product quality control	Peer reviews Intergroup coordination Software product engineering Integrated software management Training program Organization process definition Organization process focus
2 Repeatable	Management oversight and tracking of project; stable planning and product baselines	Software configuration management Software quality assurance Software subcontract management Software project tracking and oversight Software project planning Requirements management
1 Initial		

Figure B-1 Key Process Areas of the Capability Maturity Model

Figure B-2, taken from Paulk, Curtis, Chrissis, et al's *Capability Maturity Model for Software* [Paulk 91], provides an example of how the concepts of maturity level, key process area.

and goal relate to one another in the CMM, using the KPA of software project planning as the context.

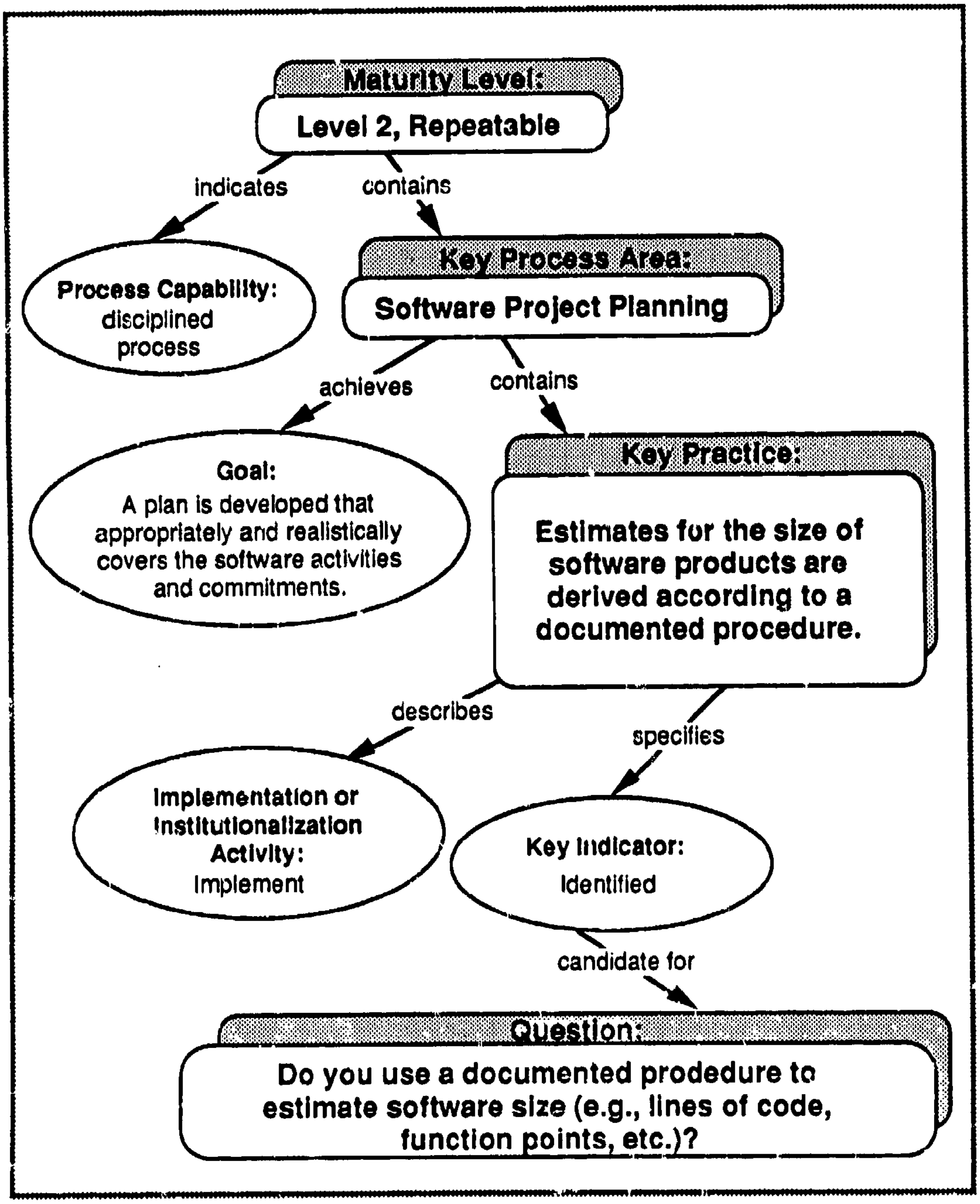

Figure B-2 CMM Structure Example At Level 2

Paulk, Curtis, and Chrissis provide an introduction to the Capability Maturity Model for Software [Paulk 91], and Weber, Paulk, Wise, and Withey provide an in-depth description of the goals and associated key practices for each KPA [Weber 91].

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This report focuses on the results of SEI software process assessments conducted over a four year period beginning in 1987. It characterizes the software processes used by software managers and practitioners at the assessed sites and classifies issues identified during the assessments. The basis for the characterization and classification is a software process maturity model developed by the SEI. This report contributes to the existing body of knowledge on the state of practice of software engineering in the U.S. by characterizing the sites from a software process maturity perspective and profiling site software process weaknesses. The data analyzed is drawn from SEI software process assessments of 59 government and industry software sites. This work is an analysis of existing assessment data rather than a designed study. The participating sites were not randomly selected; accordingly, they do not necessarily constitute a statistically valid sampling of the U.S. software industry.

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