Manager's Handbook for Software Development

Revision 1

NOVEMBER 1990

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

FOREWORD

The **Software Engineering Laboratory** (SEL) is an organization sponsored by the National Aeronautics and Space Administration/Goddard Space Flight Center (NASA/GSFC) and created for the purpose of investigating the effectiveness of software engineering technologies when applied to the development of applications software. The SEL was created in 1977 and has three primary organizational members: **NASA/GSFC**, Systems Development Branch; **University of Maryland**, Computer Sciences Department; **Computer Sciences Corporation**, Flight Dynamics Technology Group.

The goals of the SEL are (1) to understand the software development process in the GSFC environment; (2) to measure the effect of various methodologies, tools, and models on this process; and (3) to identify and then to apply successful development practices. The activities, findings, and recommendations of the SEL are recorded in the Software Engineering Laboratory Series, a continuing series of reports that includes this document.

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ABSTRACT

Methods and aids for the management of software development projects are presented. The recommendations are based on analyses and experiences of the Software Engineering Laboratory (SEL) with flight dynamics software development. The management aspects of the following subjects are described: organizing the project, producing a development plan, estimating costs, scheduling, staffing, preparing deliverable documents, using management tools, monitoring the project, conducting reviews, auditing, testing, and certifying.

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SECTION 1 — INTRODUCTION

This handbook is intended to be a convenient reference on software management methods and aids. The approach is to offer concise information describing

- What the methods and aids can accomplish
- When they can be applied
- How they are applied
- Where the manager can find more background or explanatory material

The management methods and aids included here are those that have proved effective in the experiences of the Software Engineering Laboratory (SEL) (Reference 1). The characteristics of software projects in the flight dynamics environment monitored by the SEL appear in the appendix to this document. The applications include attitude determination and control, orbit adjustment, maneuver planning, and general mission analysis.

HANDBOOK OVERVIEW

This document consists of seven sections organized by specific management topics:

Section 1 presents the handbook's purpose, organization, and intended audience. The **software life cycle** and key development activities are summarized.

Section 2 discusses the basic management concerns of organizing and planning in the context of software management. The production of the **software development management plan** is covered in detail.

Section 3 describes **resource estimation and allocation**. Techniques are presented for estimating size, costs, and effort. Guidelines are given for project scheduling and for staff allocation and composition.

Section 4 outlines contents, timing, and evaluation of **key documents and deliverables** in a software project.

Section 5 discusses the management aspects of software **verification, testing, and certification**.

Section 6 summarizes management **measures and aids** used in **monitoring and controlling** a software project. Key indicators of progress are listed along with warning signals and corresponding corrective measures.

Section 7 presents both the general function of **project reviews** and the specific implementation of the five major reviews. Guidelines for **auditing** a project are also introduced.

An **appendix, glossary, references,** and a **bibliography** of SEL literature conclude the handbook.

INTENDED AUDIENCE

The intended audience of this document is the software manager, who, as defined in this handbook, serves as either an administrative or technical manager. The positions overlap somewhat in their information needs.

The **administrative manager** has overall responsibility for developing software that meets requirements and is delivered on time and within budget. In the SEL environment, a Government Technical Officer or Assistant Technical Representative (ATR) generally serves in this capacity. Typically, this manager is not involved with the day-to-day technical supervision of the programmers and analysts who are developing the software. The administrative manager will be involved in the activities listed below; the corresponding handbook sections are listed alongside.

• Organizing the project	Section 2
• Estimating resources required	Section 3
• Estimating costs	Section 3
• Evaluating documents and deliverables	Section 4
• Monitoring progress	Section 6
• Evaluating results of reviews and audits	Section 7
• Certifying the final product	Section 5

The **technical manager** is responsible for direct supervision of the developers. The position is frequently filled by a contractor manager in the SEL environment; although, on some projects, a Government manager will fill this role instead. This person shares some of the activities listed for the administrative manager, especially with regard to monitoring development progress. The technical manager's activities and the corresponding handbook references are presented below.

• Producing and executing the software development/management plan	Section 2
• Estimating costs	Section 3
• Scheduling the project	Section 3
• Staffing the project	Section 3
• Directing the production of documents and deliverables	Section 4
• Using automated management aids	Section 6
• Monitoring development progress	Section 6
• Supervising technical staff	Section 6
• Ensuring software quality	Section 5
• Preparing for reviews	Section 7

A secondary audience for the handbook consists of those who serve a particular peripheral function but do not act in either of the two managerial capacities. Two examples of such specific functions are participating as an external reviewer at a scheduled review and conducting an audit of the project.

Government managers should note that there is no identifiable conflict between the material presented in this handbook and major NASA/GSFC standards.

SOFTWARE LIFE CYCLE

The process of software development is often modeled as a series of stages that define the software life cycle. In the flight dynamics environment, the life cycle is defined by the following phases:

- Requirements definition
- Requirements analysis
- Preliminary design
- Detailed design
- lmplementation
- System testing
- Acceptance testing
- Maintenance and operation

As shown in Figure 1-1, the phases divide the software life cycle into sequential time periods that do not overlap. However, the *activities* characteristic of one phase may be performed in other phases. For example, although most of the staff effort in analyzing requirements occurs during the requirements analysis phase, some of that activity continues at lower levels in later phases.

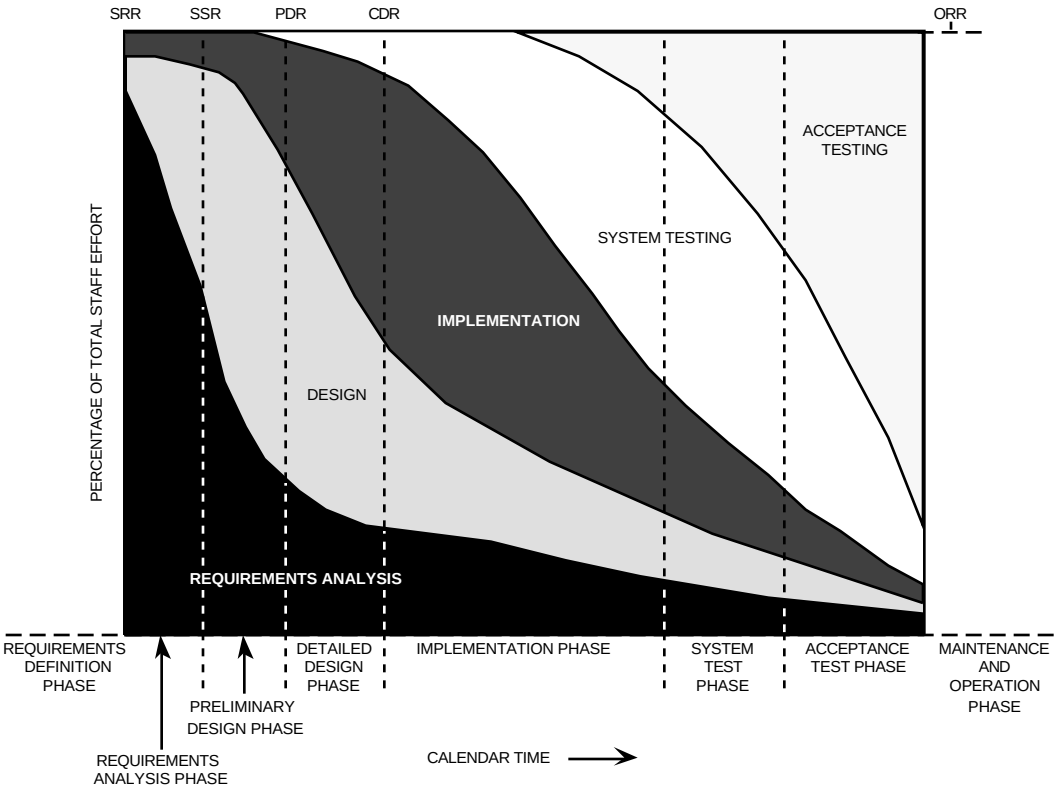


Figure 1-1. Activities by Percentage of Total Development Staff Effort

Example: At the end of the implementation phase (4th dashed line), approximately 46% of the staff are involved in system testing; approximately 15% are preparing for acceptance testing; approximately 7% are addressing requirements changes or problems; approximately 12% are designing modifications; and approximately 20% are coding, code reading, unit testing, and integrating changes. Data are shown only for the phases of the software life cycle for which the SEL has a representative sample.

The life cycle phases are important reference points for the software manager. For example, in monitoring a project, the manager may find that the key indicators of project condition at one phase are not available at other phases. Milestones in the progress of a software project are keyed to the reviews, documents, and deliverables that mark the transitions between phases. Management aids and resource estimates can be applied only at certain phases because their use depends on the availability of specific information.

In the **requirements definition** phase, a working group of analysts and developers identifies previously developed subsystems that can be reused on the current project and submits a reuse proposal. Guided by this proposal , a requirements definition team prepares the *requirements* document and completes a draft of the *functional specifications* for the system. The conclusion of this phase is marked by the *system requirements review (SRR)* at which the requirements for the system are evaluated.

During the next phase, **requirements analysis**, the development team classifies each specification and performs functional or object-oriented analysis. Working with the requirements definition team, developers resolve ambiguities, discrepancies, and to-be-determined (TBD) specifications, producing a final version of the *functional specifications* document and a *requirements analysis* report. This phase is concluded with a *software specifications review (SSR)* at which the results of the analysis are presented for evaluation.

The baselined functional specifications form a contract between the requirements definition team and the software development team and are the starting point for **preliminary design.** During this third phase, members of the development team produce a *preliminary design report* in which they define the software system architecture and specify the major subsystems, input/output (I/O) interfaces, and processing modes. The *preliminary design review (PDR)*, conducted at the end of this phase, provides an opportunity for evaluating the design presented by the development team.

In the fourth phase, **detailed design**, the system architecture defined during the previous phase is elaborated in successively greater detail, to the level of subroutines. The development team fully describes user input, system output, I/O files, and intermodule interfaces. An implementation plan is produced, describing a series of builds and releases that culminate with the delivered software system. The corresponding documentation, including complete baseline diagrams, makes up the *detailed design document.* At the *critical design review (CDR),* the detailed design is evaluated to determine if the levels of detail and completeness are sufficient for coding to begin.

During the **implementation** (code, unit testing, and integration) phase, the development team codes the required modules using the detailed design document. The system grows as new modules are coded, tested, and integrated. The developers also revise and test reused modules and integrate them into the evolving system. Implementation is complete when all code is integrated and when supporting documents (*system test plan* and draft *user's guide*) are written.

The sixth phase, **system testing**, involves the functional testing of the end-to-end system capabilities according to the system test plan. The development team validates the completely integrated system and produces a preliminary *system description* document. Successful completion of the tests required by the system test plan marks the end of this phase.

During the seventh phase, **acceptance testing**, an acceptance test team that is independent of the software development team examines the completed system to determine if the original requirements have been met. Acceptance testing is complete when all tests specified in the acceptance test plan

have been run successfully. Final versions of the *user's guide* and *system description* are published, and an *operational readiness review (ORR)* is conducted to evaluate the system's readiness to begin operational support.

The eighth and final phase, **maintenance and operation**, begins when acceptance testing ends. The system becomes the responsibility of the maintenance and operation group. The nature and extent of activity during this phase depends on the type of software developed. For some support software, the maintenance and operation phase may be very active due to the changing needs of the users.

ACTIVITIES SPANNING PHASES

In the flight dynamics environment, **reuse** and **prototyping** are key activities in several phases of the life cycle.

In the requirements definition and requirements analysis phases, **reuse analysis** is performed to determine which major segments (*subsystems*) of existing software can be utilized in the system to be developed. In the design phases, developers conduct a **verification** of this analysis by examining each reusable element individually. During the preliminary design phase, developers study major *components* to determine if they can be reused verbatim or modified. Extraction of individual *units* from a reusable software library (RSL) is conducted during the detailed design phase. A final reuse activity occurs at the end of the system test phase, at which time developers select pieces of the developed software as *candidates* for inclusion in the RSL.

Prototyping activities are usually begun during requirements analysis and completed by the end of detailed design. A protoype is an early experimental model of a system, system component, or system function that contains enough capabilities for it to be used to establish or refine requirements or to validate critical design concepts. In the flight dynamics environment, prototypes are generally used to mitigate risks by resolving unknowns related to new technology.

Figure 1-2 shows the span of these two categories of activity in the SEL environment.

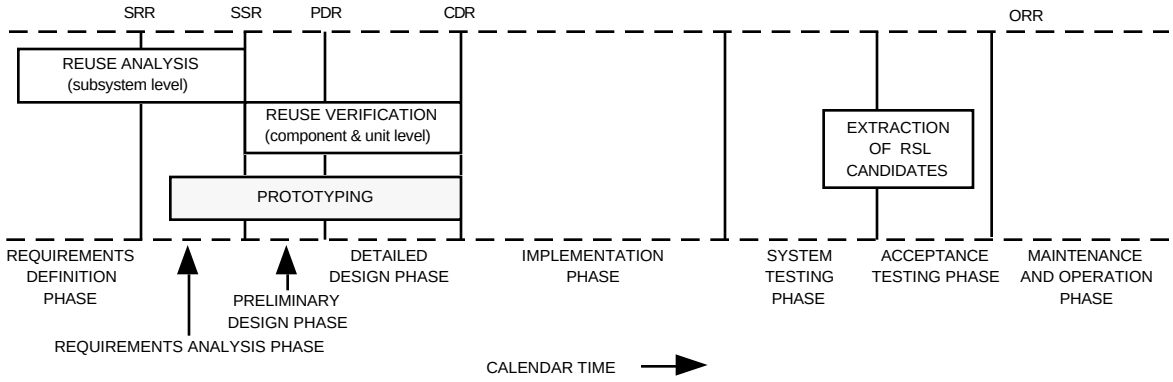


Figure 1-2. Reuse and Prototyping Activities Within the Life Cycle

The management methods and aids in this handbook are associated with the phases from requirements definition through acceptance testing. Reference 2 contains a more detailed explanation of life cycle phases and activities.

SECTION 2 — ORGANIZING AND PLANNING

The key to successful software management is to generate a realistic, usable plan and then follow it. The critical early stages of organizing and planning lay the foundation for effective project management and control.

ORGANIZING THE PROJECT

To get started, the manager must gain a clear understanding of the scope of the project and must establish the basis for control. The major initial concerns relate to clarifying the requirements, the deliverables, and the organizational framework. By addressing the four sets of questions below, the manager will acquire an understanding of the key elements that will affect project planning.

Identifying the Requirements

What functions must the system perform?
How will the system be operated?
Are the boundaries of the system visible?
In what form does the job definition exist?
Is the current job definition understandable?
Does the project depend on external events or activities?

Identifying the Products and Deliverables

What documents, programs, and files are specified as deliverable products?
When must they be delivered?
In what form are the deliverables, e.g., draft copies or on tape?
Who will receive the deliverables and accept the final product?
What criteria will be used to judge the acceptability of the final product?

Preparing for Control

Is there a timetable for periodic reporting of project status?
What is the procedure for incorporating requirements changes that affect the scope of the work?
What reviews will be necessary to mark the transitions between phases?
Are there technical or managerial risks to successful completion of the project?
What measures will be used to assess project health?

Establishing an Organizational Identity

Who will be the key contact people from the customer, developer, and support groups?
Do the different groups understand their areas of project responsibility?
Where will the development work be done?
Which development computers will be used?
What level of access to the computers will be required?

PRODUCING THE SOFTWARE DEVELOPMENT/MANAGEMENT PLAN

In many environments, the software management plan and the software development plan are separate policy documents with different orientations. The management plan is directed toward the broader aspects of administration and control, e.g., project-level monitoring of resource expenditures and the functioning of the configuration control board (CCB). The development plan focuses more on methods and approaches to software production, e.g., testing strategies and programming methodologies. Although these differences exist between the two plans, there is generally some material in common.

ln the flight dynamics environment of the SEL, the two plans are combined into a single document, the software development/management plan. Although the remainder of this section describes the contents of a single combined plan, the reader is encouraged to separate the contents into two plans if that is more appropriate to the needs of his/her environment. In either case, the items in this section must be formally addressed for a project to be successful.

The software development/management plan provides a disciplined approach to organizing and managing the software project. A successful plan serves as

- A structured checklist of important questions
- Consistent documentation for project organization
- A baseline reference with which to compare actual project performance and experiences
- A detailed clarification of the management approach to be used

By completing the plan early in the life cycle, the manager becomes familiar with the essential steps of organizing the development effort:

- Estimating resources
- Establishing schedules
- Assembling a staff
- Setting milestones

The plan should concentrate on information that is unique or tailored to the project at hand. If standard policies, guidelines, or procedures will be applied to an aspect of the project, the plan should reference the documents in which these are defined rather than restating them in detail. Writing the plan can begin as soon as any information about the project definition and scope becomes available. The plan should be completed by the end of the requirements analysis phase, except for information available only at later phases. If items in the software development/ management plan are missing for any reason, the manager should indicate who will supply the information and when it will be supplied.

Copies of the plan should be provided to all levels of project management and the project's technical staff.

Figure 2-l presents the suggested format and contents for the software development/management plan, including several references to sections of this handbook for detailed descriptions. The format is intended as a guide. Depending on the application environment, a different arrangement of items or the addition of new material may be appropriate.

SOFTWARE DEVELOPMENT/MANAGEMENT PLAN

Sections in italics describe material that is to be regularly added to the plan during the life of the project. Other sections should be revised and reissued if circumstances require significant changes in approach.

TITLE PAGE — document number, project and task names, report title, and report date.

LEAD SHEET — document identification numbers, project and task names, report title, customer name, preparers, contract and task identifiers, and report date.

TABLE OF CONTENTS — list of subsection titles and page numbers.

1. INTRODUCTION

1.1 Purpose — brief statement of the project's purpose.

1.2 Background — brief description that shows where the software products produced by the project fit in the overall system.

1.3 Organization and Responsibilities

1.3.1 Project Personnel — explanation and diagram of how the development team will organize activities and personnel to carry out the project: types and numbers of personnel assigned, reporting relationships, and team members' authorities and responsibilities (see Section 3 for guidelines on team composition).

1.3.2 Interfacing Groups — list of interfacing groups, points of contact, and group responsibilities.

2. STATEMENT OF PROBLEM — brief elaboration of the key requirements, the steps to be done, the steps (numbered) necessary to do it, and the relation (if any) to other projects.

3. TECHNICAL APPROACH

3.1 Reuse Strategy — description of the current plan for reusing software from existing systems.

3.2 Assumptions and Constraints — that govern the manner in which the work will be performed.

3.3 Anticipated and Unresolved Problems — that may affect the work and the expected effect on each phase.

3.4 Development Environment — target development machine and programming languages.

3.5 Activities, Tools, and Products — for each phase, a matrix showing: a) the major activities to be performed, b) the development methodologies and tools to be applied, and c) the products of the phase (see Section 4). Includes discussion of any unique approaches or activities.

3.6 Build Strategy — what portions of the system will be implemented in which builds and the rationale. *Updated at the end of detailed design and after each build.*

4. MANAGEMENT APPROACH

4.1 Assumptions and Constraints — that affect the management approach, including project priorities.

4.2 Resource Requirements — tabular lists of estimated levels of resources required, including estimates of system size (new and reused LOC and modules), staff effort (managerial, programmer, and support) by phase, training requirements, and computer resources (see Section 3). Includes estimation methods or rationale used. *Updated estimates are added at the end of each phase.*

Figure 2-1. Software Development/Management Plan Contents (1 of 2)

4.3 **Milestones and Schedules** — list of work to be done, who will do it, and when it will be completed. Includes development life cycle (phase start and finish dates); build/release dates; delivery dates of required external interfaces; schedule for integration of externally developed software and hardware; list of data, information, documents, software, hardware, and support to be supplied by external sources and delivery dates; list of data, information, documents, software, and support to be delivered to the customer and delivery dates; and schedule for reviews (internal and external). *Updated schedules are added at the end of each phase.*

4.4 **Metrics** — a table showing, by phase, which metrics will be collected to capture project data for historical analysis and which will be used by management to monitor progress and product quality (see Section 6 and Reference 3). If standard metrics will be collected, references to the relevant standards and procedures will suffice. Describes any measures or data collection methods unique to the project.

4.5 **Risk Management** — statements of each technical and managerial risk or concern and how it is to be mitigated. *Updated at the end of each phase to incorporate any new concerns.*

5. PRODUCT ASSURANCE

5.1 **Assumptions and Constraints —** that affect the type and degree of quality control and configuration management to be employed.

5.2 **Quality Assurance (QA)** — table of methods and standards used to ensure the quality of the development process and products (by phase). Where these do not deviate from published methods and standards, the table references the appropriate documentation. Means of ensuring or promoting quality that are innovative or unique to the project are described explicitly. Identifies the person(s) responsible for QA on the project, and defines his/her functions and products by phase.

5.3 **Configuration Management (CM)** — table showing products controlled, tools and procedures used to ensure the integrity of the system configuration: when the system is under control, how changes are requested, who makes the changes, etc. Unique procedures are discussed in detail. If standard CM practices are to be applied, references to the appropriate documents are sufficient. Identifies the person responsible for CM and describes this role. *Updated before the beginning of each new phase with detailed CM procedures for the phase, including naming conventions, CM directory designations, reuse libraries, etc.*

6. REFERENCES

7. PLAN UPDATE HISTORY — *development plan lead sheets from each update indicating which sections were updated.*

Figure 2-1. Software Development/Management Plan Contents (2 of 2)

EXECUTING THE SOFTWARE DEVELOPMENT/MANAGEMENT PLAN

The plan will be an effective management aid only to the extent that it is followed. The manager must direct and control the execution of the plan by

- Maintaining it
- Measuring progress and performance
- Recognizing danger signals .
- Taking corrective action to solve problems

At the end of each development phase or build, the manager should reestimate project size, effort, and schedule for inclusion in the software development/management plan. Earlier estimates should not be removed from the plan. They provide a record of the planning process that will be needed for the software development history (Section 4). From this information, the organization can determine which estimation methods were effective and should be used again.

When it is effectively maintained, the development plan documents the current strategy for the software development effort. By providing a uniform characterization of the project, the plan can be invaluable if changes occur in team leadership.

Significant revisions to the plan should not be considered routine maintenance. Effort should be invested when the plan is written to ensure that it is realistic, rather than continually modifying it to agree with actual decisions or experiences. Major shifts in technical approach or use of methodologies, for example, should occur only if necessary.

By measuring progress, the manager discovers whether the development/management plan is effective or not. Section 6 of this handbook addresses the types of metric data that should be collected and maintained as a record of project status.

Metric data alone are not sufficient for gauging the effectiveness of the plan, but by comparing these data to nominal values from related applications, some assessment is possible. Section 3 provides guidelines on resources and staffing that enable some comparison with the actual project data. The use of a project histories data base, as explained in Section 6, is another management aid for measuring progress.

SECTION 3 — COST ESTIMATING, SCHEDULING, AND STAFFING

This section presents methods for managing and estimating the resources required for the software project. Two of the most critical resources are **development staff** and **time**. The software manager is concerned with how much time will be required to complete the project and what staffing level will be necessary over the development cycle. Both staff and time are estimated using the procedures discussed in this section. Issues of staff size and composition over the life cycle are considered. Guidelines are provided for estimating some additional important cost elements such as computer utilization and system documentation. Reference 4 provides the background and rationale for software cost estimation.

A cautionary note applies to the cost factors throughout this section. The values summarized in the appendix to this document reflect SEL experiences in developing software for the flight dynamics environment. **Readers of this handbook should assess how well that summary matches their own software development environment** as an indication of the degree of confidence to place in the particular cost values presented. A prudent plan is to use the values here as a first approximation and begin collecting data (see Reference 3) to obtain cost factors that are representative of the reader's environment.

ESTIMATING DEVELOPMENT COST AND SCHEDULE

An understanding of the expected schedule consumption and effort expenditure in each phase of the life cycle is essential to managers. Figure l-l and Table 3-l present these distributions as they reflect projects monitored by the SEL. Because the cost of developing software is often expressed in units of effort (e.g., staff-months) to avoid the effects of inflation and salary variation, cost and effort will be used interchangeably in this section when accounting for the expenditure of staff resources.

Table 3-1. Distribution of Time Schedule and Effort Over Phases

PHASE	PERCENT OF TIME SCHEDULE	PERCENT OF EFFORT
Requirements Analysis	12	6
Preliminary Design	8	8
Detailed Design	15	16
Implementation	30	40
System Testing	20	20
Acceptance Testing	15	10

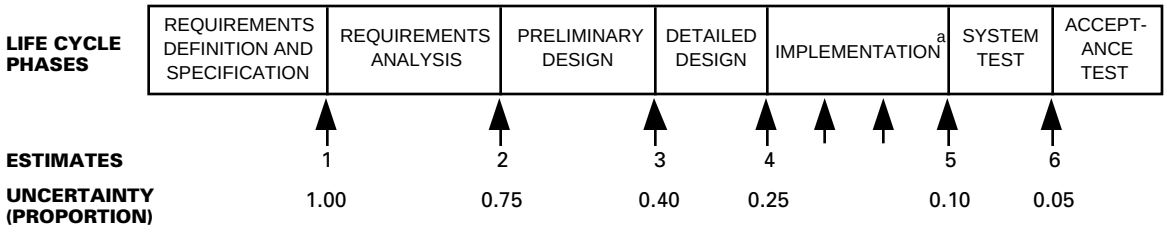
Although it is the most uncertain, the initial estimate is, in many ways, the most important. It occurs at such an early stage (after the requirements definition activity) that the temptation is strong to ignore it; to do so is a mistake. Making the initial estimate has the welcome side effect of leading the manager to consider the various factors bearing on the size and complexity of the development task. The initial estimate seeds the estimation process, serving as a reference value with which to compare later estimates. In view of this singular role, the following steps are suggested for achieving an initial estimate

- Decompose the requirements as far as possible. The decomposition unit at this point will probably be the subsystem.
- For each decomposition unit, identify similarities with functional units in previously developed systems and use any historical size data available from these completed systems.
- For decomposition units not strongly related to those of previous projects, use personal experience to estimate the size of units.
- Form the size estimate (in lines of code) for the entire project by adding the estimates for all the decomposition units.
- From historical data and personal experience, estimate the work rate (in lines of code per staff-month).
- Divide the size estimate by the work rate to obtain an estimate of the effort in staff-months.
- Apply the uncertainty proportion of l.0 to the size and effort estimates to obtain a range of possible values (See Figure 3-1 and Table 3-2).

After the initial estimate is made, a minimum of five reestimates (numbered 2 through 6 in Figure3-l) are prescribed. These reestimates are detailed in Table 3-2. They are based on the increasing granularity in the representation of the system during the life cycle. The uncertainties from Figure 3-1 are repeated in Table 3-2 because of their importance in transforming the individual estimates into ranges of estimated values.

The estimation factors in Table 3-2 represent average values for typical development projects monitored by the SEL. The estimates should be adjusted (before the uncertainty proportion is applied) when the manager identifies certain aspects of the problem, process, or environment that vary significantly from customary development conditions. For example, when many modules within the system will be unusually large or small due to their specialized function (e.g., in generating graphics), their estimated size should be based on previously developed modules with similar functions. In addition, any of the following conditions may strongly affect the effort necessary to complete the project: use of a new and dissimilar programming language, development by a completely inexperienced team, or the use of a new and dissimilar computer system.

The effects of some of these conditions have been estimated by the SEL. Table 3-3 provides the recommended percentage adjustment to the effort estimate due to the complexity of the problem. Table 3-4 provides an adjustment to the effort estimate for the effect of different team experience levels.



[a] Reestimates should also be made at the end of each build or release of a staged implementation.

Figure 3-1. Cost Estimation Schedule

Table 3-2. Procedures for Reestimating Size, Cost, and Schedule During Development

ESTIMATION POINT	DATA REQUIRED	SIZE ESTIMATE	COST (EFFORT) ESTIMATE	SCHEDULE/ STAFFING ESTIMATE[a]	UNCERTAINTY (PROPORTION)[b]
end of **Requirements Analysis**	Number of subsystems	Use 11000 SLOC per subsystem[c]	Use 3000 hours per subsystem[d]	Use 83 weeks per subsystem per staff member[d]	0.75
end of **Preliminary Design**	Number of units[e]	Use 190 SLOC per unit[c]	Use 52 hours per unit[d]	Use 1.45 weeks per unit per staff member[d]	0.40
end of **Detailed Design**	Number of new and extensively modified units (N) Number of reused units (R) (slightly modified and verbatim	Compute number of developed units = N + 0.2R Use developed SLOC = 200 x number of developed units	Use 0.31 hours per developed SLOC[d]	Use .0087 weeks per developed SLOC per staff member[d]	0.25
end of **Implementation**	Current size in SLOC Effort expended to date Time schedule expended to date	Add 26% to current size (for growth during testing)	Add 43% to effort already expended (for effort to complete)	Add 54% to time schedule expended (for time to complete)	0.10
end of **System Testing**	Effort expended to date	Final product size has been reached	Add 11% to effort already expended (for effort to complete)	Add 18% to time schedule expended (for time to complete)	0.05

NOTE: Parameter values are derived from three attitude ground support systems (AGSSs): GOES, GRO, and COBE.

[a] Schedule/staffing values are based on a full-time employee's average work week, with adjustments for holidays, leave, etc. (1864 hours annually). The values provided can be used to determine either schedule or staff level, depending on which parameter is given.

[b] Of size and effort estimates: Upper limit = (size or effort estimate) x (1.0 + uncertainty). Lower limit = (size or effort estimate)/ (1.0 + uncertainty). To allow for TBD requirements, staff turnover, etc., conservative management practice dictates the use of estimates that lie between the estimated value and the upper bound. SEL managers, for example, generally plan for a 40% increase in estimated system size from PDR to project end due to changing requirements.

[c] Source line of code: a single line of executable or nonexecutable source code (including comments and embedded blank lines).

[d] Estimates of total effort (or time). Subtract effort (or time) already expended to get effort (or time) to complete.

[e] Unit: a named software element that is independently compilable, e.g., a subroutine, subprogram, or function.

Table 3-3. Complexity Guideline

PROJECT TYPE[a]	ENVIRONMENT TYPE[b]	EFFORT MULTIPLIER
Old	Old	1.0
Old	New	1.4
New	Old	1.4
New	New	2.3

[a] Application, e.g., orbit determination, simulator. The project (or portion of the project) type is old when the organization has more than 2 years experience with it.

[b] Computing environment, e.g., IBM 4341, VAX 8810. The environment type is old when the organization has more than 2 years of experience with it on average.

Table 3-4. Development Team Experience Guideline

TEAM YEARS OF APPLICATION EXPERIENCE[a]	EFFORT MULTIPLIER
10	0.5
8	0.6
6	0.8
4	1.0
2	1.4
1	2.6

[a] Average of team member's years of application experience weighted by member's participation on the team. Application experience is defined as prior work on similar applications, e.g., attitude and orbit determination. Member's participation is defined as time spent working on the project as a proportion of total project effort.

PROJECT STAFFING

Although the average level of staff is provided by the effort estimate, more specific guidelines are available for three aspects of staffing — **team size, staffing pattern, and team composition**. Typical staffing profiles are provided in Section 6. Table 3-5 presents guidelines for team size in terms of the team leader's experience. Table 3-6 addresses team composition, listing recommended percentages of senior personnel and analysts.

Table 3-5. Team Size Guideline

TEAM LEADER: MINIMUM YEARS OF EXPERIENCE [a]			MAXIMUM TEAM SIZE EXCLUDING TEAM LEADER
Applicable	Organization	Leadership	
6	4	3	7 ± 2
5	3	1	4 ± 2
4	2	0	2 ± 1

[a] Applicable = Applicable experience (requirements definition, analysis, development, maintenance, and operation).
Organization = Experience with the organization and its development methodology.
Leadership = Experience as a team leader or manager.

Examples: A team leader with no leadership experience should not be asked to manage a team with greater than three members. A team of seven to nine members should be provided with a leader who has six years or more of experience with the application, primarily within the organization.

Table 3-6. Guideline for Development Team Composition

PROJECT TYPE [a]	ENVIRONMENT TYPE [a]	PERCENTAGE OF SENIOR PERSONNEL [b]	PERCENTAGE OF ANALYSTS [c]
Old	Old	25-33	25-33
Old	New	33-50	25-33
New	Old	33-50	33-50
New	New	50-67	33-50

[a] The project and environment types are old when the development team has, on average, more than 2 years experience with them.
[b] Senior personnel are those with more than 5 years of experience in development-related activities.
[c] Analysts are those personnel who have training and an educational background in problem definition and solution with the application (project type).

OTHER SOFTWARE DEVELOPMENT COSTS

Estimates and guidelines are presented for other software cost elements: **computer utilization, system documentation, software rehosting, software reuse,** and **software maintenance**.

Cost of Computer Utilization

This cost may be expressed in terms of system size. The estimate of total hours of CPU time, H, in a NAS 8040 environment is **H = 0.0008L**, where L is the number of lines of source code in the system. (The NAS 8040 is comparable to an IBM 3033). The estimated number of runs, R, in the same SEL environment is **R = 0.29L**. Figures 3-2 and 3-3 show computer utilization over the life cycles of recent projects monitored by the SEL.

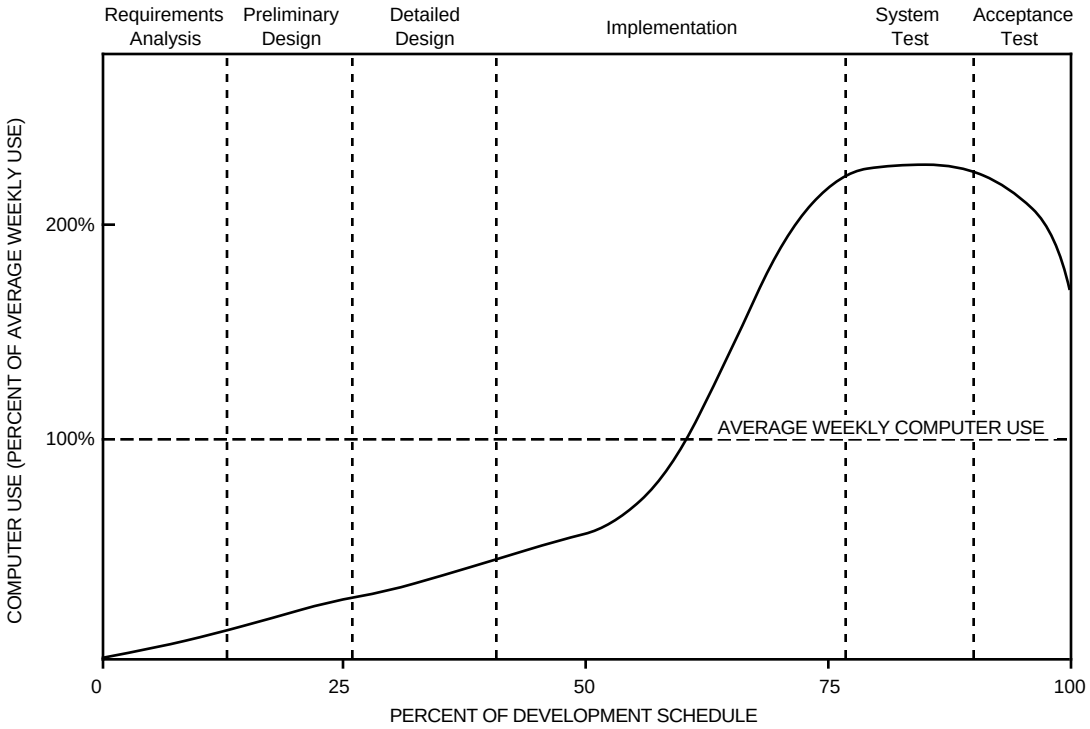


Figure 3-2. Typical Computer Utilization Profile (FORTRAN Projects)

- In comparison to FORTRAN, Ada projects utilize a larger percentage of CPU early in the life cycle
- PDL and prolog are compiled during the design phases
- Integration testing is conducted throughout the implementation phase

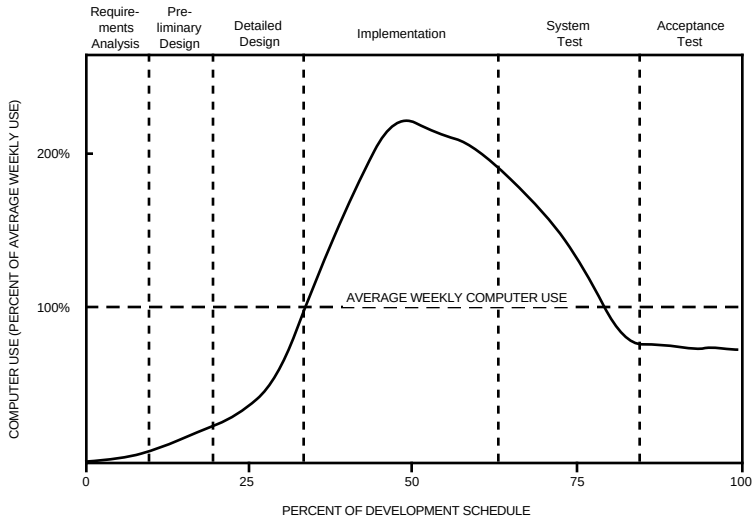


Figure 3-3. Typical Computer Utilization Profile (Ada Projects)

Cost of System Documentation

Documentation cost is included in the cost estimates of Table 3-2. The average quantity of documentation for a given software development project can be estimated using the formula **P = 120 + 0.026 L**,where P is pages of documentation and L is source lines of code. This cost covers a requirements analysis report, design documents, system description, and user's guide. For a separate documentation task, 4 staff-hours per page may be used to estimate the total cost of system documentation.

Cost of Rehosting Software

Rehosting means modifying existing software to operate on a new computer system. Testing will require a high percentage of the total effort of any rehost project. Table 3-7 provides the cost of rehosting high-level language software as a percentage of the original development cost in staff-hours.

Table 3-7. Cost of Rehosting Software

SYSTEM'S RELATIONSHIP	RELATIVE COST[a]		TESTING EFFORTS[b]		NEW CODE[c]
	FORTRAN	ADA	FORTRAN	ADA	
Compatible[d]	10-16	5-11	55-70	36-40	0-3
Similar[e]	15-18	10-15[f]	45-55[f]	30-35[f]	4-14
Dissimilar[g]	20-40	18-30	40-50	25-30	15-32

[a] Percent of original development cost.
[b] Percent of total rehosting cost.
[c] Percent of code that must be newly developed or extensively modified.
[d] Compatible: Systems designed to be plug compatible, (e.g., IBM S/360 and 4341).
[e] Similar: Some key architectural characteristics, (e.g., word size) are shared and some are different (e.g., IBM 4341 and VAX 8810).
[f] Data extracted from Reference 5.
[g] Dissimilar: Differences in most characteristics of architecture and organization (e.g., IBM S/360 and PDP 11/70).

Cost of Reusing Software

Reusable modules should be identified during the design stage. As shown in Table 3-8, the estimated cost to reuse a module depends on the extent of the changes.

Table 3-8. Cost of Reusing Software

MODULE CLASSIFICATION	PERCENT OF MODULE'S CODE MODIFIED OR ADDED	RELATIVE COST [a]
New	100	100
Extensively Modified	>25	100
Slightly Modified	1-25	20
Old	0	20

[a] Cost as a percent of the cost to develop a new module.

Cost of Software Maintenance

Software maintenance refers to three types of activities occurring after the software is delivered — **correcting defects** detected during operational use, **making enhancements** that improve or increase functionality, and **adapting the software** to changes in the operational environment, such as a new operating system or compiler.

Expected maintenance costs vary widely, depending on the quality of the delivered software and the stability of the operational environment. In the environment monitored by the SEL, a large percentage of the maintenance effort of FORTRAN systems is expended in enhancing the system. This includes modifying existing components, retesting, regenerating, and recertifying the software. Few new components are added, and new documentation is generally not produced. Average annual maintenance effort ranges from 1 to 23% of the total development cost (in staff-hours) of the original system. Total maintenance over the life of the project costs from 1.5 to 24 staff-years per million LOC (see Reference 6).

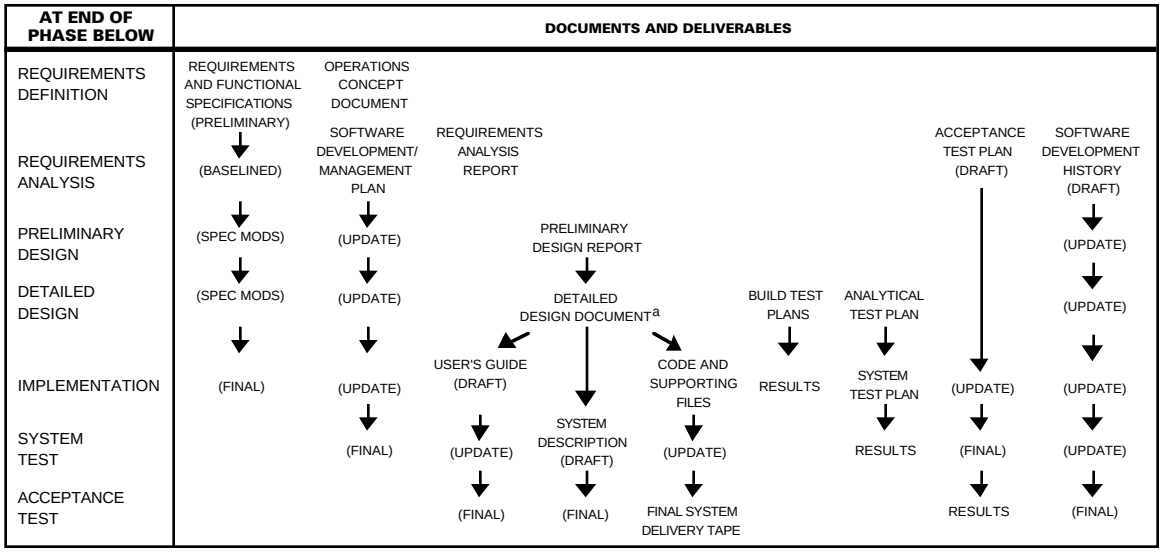
Because maintenance effort varies so widely, the SEL recommends that estimates of the annual cost of maintenance be adjusted based on project type. The SEL uses 5% of total development cost as the estimate of annual maintenance of stable systems with a short life expectancy (less than 4 years). Annual maintenance of larger, longer lived systems is estimated at 15% of development cost.

SECTION 4—KEY DOCUMENTS AND DELIVERABLES

Documents and deliverables provide an ongoing system description and serve as key indicators of progress. They are a central concern of software managers because they mark the transitions between life cycle phases. The following documents and deliverables are of specific interest to the software manager:

- Requirements and functional specifications
- Operations concept document
- Software development/management plan
- Requirements analysis report
- Preliminary design report
- Detailed design document
- Test plans
- User's guide
- System description
- Software development history
- System delivery tape — software product and supporting files and tools

The documents and deliverables associated with a software development project are keyed to life cycle phases. Figure 4-l shows the phases when they should be completed. In some instances, preliminary versions are prepared, followed by updates. For any point in the life cycle, the software manager can determine what documents and deliverables should be in preparation. This section presents the recommended document contents as well as management guidelines for evaluating completed documents.



[a] The preliminary design report evolves into the detailed design document. Descriptive material in the detailed design document provides the basis for the system description. Updated prologs and program design language (PDL) from the detailed design are delivered with the final system and operations scenarios and performance information are included in the user's guide.

Figure 4-1. Key Documents and Deliverables by Phase

SUGGESTED DOCUMENT CONTENTS

For each document, a suggested format and contents are given (see Figures 4-2 through 4-10), with the exception of the software development/management plan, which was covered separately in Section 2. The actual contents of the documents may vary from the outlines presented here. Specific features of the application environment may lead the manager to exercise judgment in selecting the material that is most appropriate and effective. This allowance for flexibility should be understood when examining the following figures.

REQUIREMENTS AND FUNCTIONAL SPECIFICATIONS

This document is produced by the requirements definition team as the key product of the requirements definition phase. It is often published in multiple volumes: volume 1 defines the requirements, volume 2 contains the functional specifications, and volume 3 provides mathematical specifications. The document is distributed prior to the SRR. Functional specifications are updated during requirements analysis and baselined following the SSR.

1. **Introduction**
   a. Purpose and background of the project
   b. Document organization
2. **System overview**
   a. Overall system concept
   b. Expected operational environment (hardware, peripherals, etc.)
   c. High-level diagrams of the system showing the external interfaces and data flows
   d. Overview of high-level requirements
3. **Requirements** — functional, operational (interface, resource, performance, etc.), and data requirements
   a. Numbered list of high-level requirements with their respective derived requirements (derived requirements are not explicitly called out in the requirements document but represent constraints, limitations, or implications that must be satisfied to achieve the explicitly stated requirements)
   b. For each requirement:
      (1) Requirement number and name
      (2) Description of the requirement
      (3) Reference source for the requirement, distinguishing derived from explicit requirements
      (4) Interfaces to other major functions or external entities
      (5) Performance specifications — frequency, response time, accuracy, etc.
4. **Functional specifications**
   a. Discussion and diagrams showing the functional hierarchy of the system
   b. Description and data flow diagrams of the basic functions of each major subsystem
   c. Description of general conventions used (mathematical symbols, units of measure, etc.)
   d. Description of each basic function
      (1) Input
      (2) Process — detailed description on how this function should work
      (3) Output
      (4) Identification of candidate reusable software
      (5) Acceptance criteria for verifying satisfaction of related requirements
      (6) Data dictionary — indicating name of item, definition, structural composition of the item, item range, item type
5. **Mapping of functional specifications to requirements** — also distinguishes project-unique requirements from standard requirements for the project type (AGSS, dynamics simulator, etc.)
6. **Mathematical specifications** — formulae and algorithm descriptions to be used in implementing the computational functions of the system
   a. Overview of each major algorithm
   b. Detailed formulae for each major algorithm

Figure 4-2. Requirements and Functional Specifications Contents

OPERATIONS CONCEPT DOCUMENT

This document provides a top-down view of the system from the user's perspective by describing the behavior of the system in terms of operational methods and scenarios. It should be provided by analysts to the development team by the end of the requirements definition phase. The suggested contents are as follows:

1. **Introduction**, including purpose and background of the system
   a. Overall system concept
   b. System overview with high-level diagrams showing the external interfaces and data flow
   c. Discussion and diagrams showing the functional hierarchy of the system
   d. Document organization

2. **Operational environment**, description and high-level diagrams of the environment in which the system will be operated
   a. Overview of operating scenarios
   b. Description and diagrams of the system configuration (hardware and software)
   c. Description of the responsibilities of the operations personnel

3. **Operational modes**
   a. Discussion of the system's modes of operation (e.g., critical vs. normal, launch vs. on-orbit operations)
   b. Volume and frequency of data to be processed in each mode
   c. Order, frequency, and type (e.g., batch or interactive) of operations in each mode

4. **Operational description of each major function** or object in the system
   a. Description and high-level diagrams of each major operational scenario showing all input, output, and critical control sequences
   b. Description of the input data, including the format and limitations of the input. Sample screens (i.e., displays, menus, popup windows, etc.) depicting the state of the function before receiving the input data should also be included
   c. Process — high-level description on how this function will work
   d. Description of the output data, including the format and limitations of the output. Samples (i.e., displays, reports, screens, plots, etc) showing the results after processing the input should also be included
   e. Description of status and prompt messages generated during processing, including guidelines for user responses to any critical messages

5. **Requirements traceability matrix** mapping each operational scenario to requirements

Figure 4-3. Operations Concept Document Contents

REQUIREMENTS ANALYSIS REPORT

This report is prepared by the development team at the conclusion of the requirements analysis phase. It summarizes the results of requirements analysis and establishes a basis for beginning preliminary design. The suggested contents are as follows:

1. **Introduction —** purpose and background of the project, overall system concepts, and document overview

2. **Reuse proposal** — key reuse candidates and overall architectural concept for the system

3. **Operations overview** — updates to operations concepts resulting from work performed during the requirements analysis phase
   a. Updated operations scenarios
   b. Operational modes — including volume and frequency of data to be processed in each mode, order and type of operations, etc.
   c. Updated descriptions of input, output, and messages

4. **Specification analysis**
   a. Summary of classifications (mandatory, derived, "wish list", information only, or TBD) assigned to requirements and functional specifications
   b. Problematic specifications — identification and discussion of conflicting, ambiguous, infeasible, untestable, and TBD requirements and specifications
   c. Unresolved requirements/operations issues, including the dates by which resolutions are needed
   d. Analysis of mathematical algorithms

5. **System constraints**
   a. Hardware availability — execution, storage, peripherals
   b. Operating system limitations
   c. Support software limitations

6. **Development assumptions**

7. **Risks**, both to costs and schedules. These should include risks related to TBD or changing requirements, as well as technical risks

8. **Prototyping efforts** needed to resolve technical risks, including the goals and schedule for each prototyping effort

9. **Data flow or object-oriented diagrams** — results of all functional decomposition or object-oriented analysis of the requirements performed during the requirements analysis phase

10. **Data dictionary** — for the updated processes, data flows, and objects shown in the diagrams

Figure 4-4. Requirements Analysis Report Contents

PRELIMINARY DESIGN REPORT

This report is prepared by the development team as the primary product of the preliminary design phase. It presents the functional description of the system and forms the basis for the detailed design document. The suggested contents are as follows:

1. **Introduction** — purpose and background of the project, overall system concepts, and document overview
2. **Design overview**
   a. Design drivers and their order of importance (e.g., performance, reliability, hardware, memory considerations, operating system limitations, language considerations,etc.)
   b. Results of reuse tradeoff analyses; the reuse strategy
   c. Critique of alternative designs
   d. Discussion and high-level diagrams of the selected system design, showing hardware interfaces, external data interfaces, interconnections among subsystems, and data flow
   e. A traceability matrix of the subsystems against the requirements
   f. Design status
      (1) List of constraints, concerns, and problem areas and their effects on the design
      (2) List of assumptions and possible effects on design if they are wrong
      (3) List of TBD requirements and an assessment of their effect on system size, required effort, cost, and schedule
      (4) ICD status
      (5) Status of prototyping efforts
   g. Development environment (i.e., hardware, peripheral devices, etc.)
3. **Operations overview**
   a. Operations scenarios/scripts (one for each major product that is generated). Includes the form and volume of the product and the frequency of generation. Panels and displays should be annotated to show what various selections will do and should be traced to a subsystem
   b. System performance considerations
4. **Design description** for each subsystem or major functional breakdown:
   a. Discussion and high-level diagrams of subsystem, including interfaces, data flow, and communications for each processing mode
   b. High-level description of input and output
   c. High-level description of processing keyed to operator-specified input and actions in terms of points of control, functions performed, and results obtained (both normal and abnormal, i.e., error processing and recovery)
   d. Structure charts or object-oriented diagrams expanded to two levels below the subsystem driver
   e. Prologs (specifying the module's purpose, operation, calling sequence arguments, external references, etc; Ada projects should provide package specifications for the principle objects in the system) and program design language (PDL) for each module through the first level below subsystem driver. (Prologs and PDL are normally published in a separate volume because of size.)
5. **Data interfaces** for each internal and external interface:
   a. Description, including name, function, frequency, coordinates, units, and computer type, length, and representation
   b. Format
      (1) Organization and description of files (i.e., data files, tape, etc.)
      (2) Layout of frames, samples, records, blocks, and/or transmissions
      (3) Storage requirements

Figure 4-5. Preliminary Design Report Contents

DETAILED DESIGN DOCUMENT

This document is the primary product of the detailed design phase. To complete the document, the development team updates similar material from the preliminary design report and adds greater detail. The suggested contents are as follows:

1. **Introduction** — purpose and background of the project, overall system concepts, and document overview
2. **Design overview**
   a. Design drivers and their order of importance
   b. Reuse strategy
   c. Discussion and high-level diagrams of the selected system design, showing hardware interfaces, external data interfaces, interconnections among subsystems, and data flow
   d. Traceability matrix of major components against requirements and functional specifications
   e. Design status
      (1) List of constraints, concerns, and problem areas and their effects on the design
      (2) List of assumptions and possible effects on design if they are wrong
      (3) List of TBD requirements and an assessment of their effect on system size, required effort, cost, and schedule
      (4) ICD status
      (5) Status of prototyping efforts
   f. Development environment
3. **Operations overview**
   a. Operations scenarios/scripts
   b. System performance considerations
4. **Design description** for each subsystem or major functional breakdown:
   a. Overall subsystem capability
   b. Assumptions about and restrictions to processing in each mode
   c. Discussion and high-level diagrams of subsystem, including interfaces, data flow, and communications for each processing mode
   d. High-level description of input and output
   e. Detailed description of processing keyed to operator-specified input and actions in terms of points of control, functions performed, and results obtained (both normal and abnormal, i.e., error processing and recovery)
   f. Structure charts or object-oriented diagrams expanded to the subprogram level, showing interfaces, data flow, interactive control, interactive input and output, and hardcopy output
   g. Internal storage requirements, i.e., description of arrays, their size, their data capacity in all processing modes, and implied limitations of processing
   h. Detailed input and output specifications
      (1) Processing control parameters, e.g., NAMELISTS
      (2) Facsimiles of graphic displays for interactive graphic systems
      (3) Facsimiles of hardcopy output
   i. List of numbered error messages with description of system's and user's actions
   j. Description of COMMON areas or other global data structures
   k. Prologs or Ada package specifications and PDL for each unit (normally kept in a separate document because of size)
5. **Data interfaces**—updated from description in preliminary design report

Figure 4-6. Detailed Design Document Contents

TEST PLANS

BUILD/RELEASE TEST PLAN

- Prepared by the system test team during the detailed design phase
- Designed to test the functional capability of each build or release (functional subsets of the complete software system) as defined in the software development/management plan and to identify limitations
- Executed during the implementation phase by the system test team as soon as unit testing and integration of each build/release is complete

ANALYTICAL TEST PLAN

- Prepared prior to the implementation phase by the analysts who will use the system
- Designed to assist developers in verifying the results of complex mathematical and astronomical calculations performed by the system
- Unit level tests are executed during the implementation phase by developers; end-to-end tests are executed as a part of system testing

SYSTEM TEST PLAN

- Prepared by the system test team during the implementation phase
- Designed to verify the system's end-to-end processing capability, as specified in the requirements document, and to identify limitations
- Executed during the system testing phase by the system test team

ACCEPTANCE TEST PLAN

- Drafted by the acceptance test team following the requirements definition phase, based on the requirements and functional specifications document
- Designed to demonstrate the system's compliance with the requirements and functional specifications
- Executed during the acceptance testing phase by the acceptance test team

TEST PLAN OUTLINE

1. Introduction, including purpose, type and level of testing, and schedule
2. Traceability matrix mapping each requirement and functional specification to one or more test cases
3. Test description (normally the length need not exceed 1 to 2 pages) for each test
   a. Purpose of test, i.e., specific capabilities or requirements tested
   b. Detailed specification of input
   c. Required environment, e.g., data sets required, computer hardware necessary
   d. Operational procedure, i.e., how to do the test
   e. Detailed specification of output, i.e., the expected results
   f. Criteria for determining whether or not the test results are acceptable
   g. Section for discussion of results, i.e., for explaining deviations from expected results and identifying the cause of the deviation or for justifying the deviation

Figure 4-7. Contents of Test Plans

USER'S GUIDE

The development team begins preparation of the user's guide during the implementation phase. Items 1 and 2, and portions of item 3, represent updated material from the detailed design document, although some rewriting is expected to make it more accessible to the user. A draft is completed by the end of the implementation phase and is evaluated during system testing. At the beginning of the acceptance test phase, an updated version is supplied to the acceptance test team for evaluation. Corrections are incorporated, and a final revision is produced at the end of the phase. The suggested contents are as follows:

1. **Introduction**
   a. Overview of the system, including purpose and background
   b. Document organization
   c. Discussion and high-level diagrams of system showing hardware interfaces, external data interfaces, software architecture, and data flow
2. **Operations overview**
   a. Operations scenarios/scripts
   b. Overview and hierarchy of displays, windows, menus, reports, etc.
   c. System performance considerations
3. **Description** for each subsystem or major functional capability:
   a. Overall subsystem capability
   b. Assumptions about and restrictions to processing in each mode
   c. Discussion and high-level diagrams of subsystems, including interfaces, data flow, and communications for each processing mode
   d. High-level description of input and output
   e. Detailed description of processing keyed to operator-specified input and actions in terms of points of control, functions performed, and results obtained (both normal and abnormal, i.e., error processing and recovery)
   f. For interactive subsystems, facsimiles of displays in the order in which they are generated
   g. Facsimiles of hardcopy output in the order in which it is produced, annotated to show what parameters control it
   h. List of numbered messages with explanation of system's and user's actions annotated to show the subroutines that issue the message
4. **Requirements for execution**
   a. Resources — discussion, high-level diagrams, and tables for system and subsystems
      (1) Hardware
      (2) Data definitions, i.e., data groupings and names
      (3) Peripheral space considerations — data storage and printout
      (4) Memory considerations — program storage, array storage, and data set buffers
      (5) Timing considerations
         (a) Central processing unit (CPU) time in terms of samples and cycles processed
         (b) I/O time in terms of data sets used and type of processing
         (c) Wall-clock time in terms of samples and cycles processed
   b. Run information — control statements for various processing modes
   c. Control parameter information — by subsystem, detailed description of all control parameters (e.g., NAMELISTS), including name, computer type, length, and representation, and description of parameter with valid values, default value, units, and relationship to other parameters

Figure 4-8. User's Guide Contents

SYSTEM DESCRIPTION

During the implementation phase, the development team begins work on the system description by updating data flow/object diagrams and structure charts from the detailed design. A draft of the document is completed during the system testing phase and a final version is produced by the end of acceptance testing. The suggested contents are as follows:

1. **Introduction** — purpose and background of the project, overall system concepts, and document overview
2. **System overview**
   a. Overview of operations scenarios
   b. Design drivers (e.g., performance considerations) and their order of importance
   c. Reuse strategy
   d. Results of prototyping efforts
   e. Discussion and high-level diagrams of the selected system design, showing hardware interfaces, external data interfaces, interconnections among subsystems, and data flow
   f. Traceability matrix of major components against requirements and functional specifications
3. **Description** of each subsystem or major functional breakdown:
   a. Overall subsystem capability
   b. Assumptions about and restrictions to processing in each mode
   c. Discussion and high-level diagrams of subsystem, including interfaces, data flow, and communications for each processing mode
   d. High-level description of input and output
   e. Structure charts or object-oriented diagrams expanded to the subprogram level, showing interfaces, data flow, interactive control, interactive input and output, and hardcopy output
4. **Requirements for creation**
   a. Resources — discussion, high-level diagrams, and tables for system and subsystems
      (1) Hardware
      (2) Support data sets
      (3) Peripheral space considerations — source code storage, scratch space, and printout
      (4) Memory considerations — program generation storage and data set buffers
      (5) Timing considerations
         (a) CPU time in terms of compile, build, and execute benchmark test
         (b) I/O time in terms of the steps to create the system
   b. Creation information — control statements for various steps
   c. Program structure information — control statements for overlaying or loading
5. **Detailed description of input and output** by step — source code libraries for system and subsystems, object code libraries, execution code libraries, and support libraries
6. **Internal storage requirements** — description of arrays, their size, their data capacity in all processing modes, and implied limitations of processing
7. **Data interfaces** for each internal and external interface:
   a. Description, including name, function, frequency, coordinates, units, computer type, length, and representation
   b. Format — organization (e.g., indexed), transfer medium (e.g., disk), layout of frames (samples, records, blocks, and/or transmissions), and storage requirements
8. **Description of COMMON blocks,** including locations of any hard-coded physical constants
9. **Prologs/package specifications and PDL** for each subroutine (separate volume)
10. **Alphabetical list of subroutines from support data sets**, including a description of each subroutine's function and a reference to the support data set from which it comes

Figure 4-9. System Description Contents

SOFTWARE DEVELOPMENT HISTORY

Material for the development history is collected by the project leader throughout the life of the project. At the end of the requirements analysis phase, project data and early lessons learned are compiled into an initial draft. The draft is expanded and refined at the end of each subsequent phase so that, by the end of the project, all relevant material has been collected and recorded. The final version of the software development history is produced within 1 month of software acceptance. The suggested contents are as follows:

1. **Introduction** —purpose of system, customer of system, key requirements, development machines and language
2. **Historical overview** by phase —includes products produced, milestones and other key events, phase duration, important approaches and decisions, staffing information, and special problems
   a. Requirements definition —if requirements were produced by the software development team, this section provides an historical overview of the requirements definition phase. Otherwise, it supplies information about the origin and documentation of the system's requirements and functional specifications
   b. Requirements analysis
   c. Detailed design
   d. Implementation —coding through integration for each build/release
   e. System testing
   f. Acceptance testing
3. **Project data**
   a. Personnel and organizational structure —list of project participants, their roles, and organizational affiliation. Includes a description of the duties of each role (e.g., analyst, developer, section manager) and a staffing profile over the life of the project
   b. Schedule —table of key dates in the development of the project and a chart showing each estimate (original plus reestimates at each phase end) vs. actual schedule
   c. Project characteristics
      (1) Standard tables of the following numbers: subsystems; total, new, and reused components; total, new, adapted and reused (verbatim) SLOC, statements, and executables; total, managerial, programmer, and support effort; total productivity
      (2) Standard graphs or charts of the following numbers: project growth and change histories; development effort by phase; development effort by activity; CPU usage; system test profile; error rates; original size estimate plus each reestimate vs. final system size; original effort estimate plus each reestimate vs. actual effort required
      (3) Subjective evaluation data for the project —copy of the SEL subjective evaluation form (SEF) or report of SEF data from the project data base (see Reference 7)
4. **Lessons learned** —descriptions of the major strengths and weaknesses of the development process and product, what was learned from them, and what specific recommendations can be made to improve future projects
   a. Planning —development plan timeliness and usefulness, adherence to development plan, personnel adequacy (number and quality), etc.
   b. Requirements —completeness and adequacy for design, change history and stability, and clarity (i.e., were there misinterpretations?), etc.
   c. Development —lessons learned in design, code and unit testing
   d. Testing —lessons learned in system and acceptance testing
   e. Product assurance —adherence to standards and practices; QA and CM lessons learned
   f. New technology —impact of any new technology used by the project on costs, schedules, quality, etc. as viewed by both developers and managers, recommendations for future use of the technology

Figure 4-10. Software Development History Contents

GUIDELINES FOR EVALUATING COMPLETED DOCUMENTS

The software manager will be critically reviewing completed documents. The general guidelines presented here involve checking the degree to which five basic attributes of a successful document are present in the document under review:

Accuracy — Is the document correct? Are there obvious mistakes? Are assumptions about resources and environment valid? Is there evidence of a lack of understanding of important aspects of the problem or process?

Clarity — Is the document expressed in a form that is accessible and understandable? Are tables and diagrams used where possible instead of text?

Completeness — Is the right information included, considering the purpose of the document? Have any necessary items been omitted? When the document reflects continuing development from a previous document, does it contain all the elements from the earlier document?

Consistency — Do passages in the document contradict other passages in the same document? Do all symbols conform to a standard notation?

Level of detail — Do the contents reflect a level of detail appropriate to the purpose of the document? Is more elaboration needed in a specific area?

The following questions can be used to analyze the document for the existence and quality of essential features.

Requirements and Functional Specifications

Are all assumptions about requirements documented in the functional specifications?
Are all requirements and functional specifications testable as written?
Are performance requirements included?
Is it clear which requirements and specifications are identical or closely similar to those in existing systems?

Operations Concept Document

Are operating scenarios realistic?
Is it clear which operations concepts map to which requirements?

Requirements Analysis Report

Has the effect of TBD requirements been underestimated?
Are there additional sources of reusable software?
Are resources sufficient?

Preliminary Design Report

Have all functional specifications been allocated to subsystems?
Are all interfaces understood?
Is the rationale for the chosen design justifiable?
Is the subsystem partitioning sensible?

Detailed Design Document

Are baseline diagrams provided to the subroutine level?
Are all external files described in content and format (to the byte level)?
Are all TBD requirements resolved?
If the design is followed, will the system meet its requirements?
Is there evidence of information-hiding, i.e., localizing the data usage and access?
Is the coupling between modules low, and are the modules cohesive?

Test Plans

Do the tests describe expected results?
Are the tests repeatable, i.e., do the test specifications adequately describe the setup and environment so that two different people would produce the same tests from the test descriptions?
How well do the tests cover the range of capabilities?
Are there explicit criteria for determining whether test results are acceptable?
Is the schedule reasonable in light of test resources?

User's Guide

Will it be understandable to the users?
Is it organized so that it can serve different user populations simultaneously?
Are examples provided?
Is input described in sufficient detail?
Are status messages, error messages, and recovery explained?

System Description

Is the document structured to accommodate both those who want only a high-level view of the system and those who seek a detailed view?
Is the scope of the system clear?
Are the relationships to other systems explained?

Software Development History

Is there an update list that shows when estimates of system size, effort, schedule, and cost were made?
Have all of the problem areas been discussed?

SECTION 5 — VERIFICATION, TESTING, AND CERTIFICATION

This section summarizes recommended methods of verifying, validating, and certifying the software development process and product. Both testing and non-testing verification techniques are used to evaluate the software's function and performance so that problems can be repaired before their effects become too costly. Certification subjects the product and process to independent inspection and evaluation.

CODE READING

Code reading is a systematic procedure for reading and understanding the operation of a program. Studies have shown that code reading detects more errors at a lower cost than either functional testing or structural testing alone (Reference 8). In the experience of the SEL, the most powerful verification combination is human inspection followed by functional testing.

Purpose — Code reading is designed to verify that the code of a program unit is correct with respect to its intended function.

Participants — Code must be read by an experienced developer who is not the original programmer. The SEL recommends that two code readers be assigned to each unit, since studies have shown that only one quarter of the total errors found in code reading are found by both readers independently (Reference 9).

Activities — All developed code must be read. Unless the project is using cleanroom methodology (Reference 9), the code should be cleanly compiled beforehand. Each reader reviews the code independently. In addition to checking functionality, the reader ensures the code is consistent with the design specified in the prolog and PDL and that it conforms to standards and conventions. Detailed guidelines for code reading are provided in Section2 of Reference 10.

Monitoring — To measure progress, use total number of units coded versus number successfully read.

UNIT TESTING

Unit testing takes place only after the code has been read. All newly developed or extensively modified units must be verified via unit testing. (NOTE: Ongoing research efforts are examining significantly different approaches to testing at the unit level; see Reference 9).

A spectrum of formality and rigor exists for unit testing and integration. Especially complex or critical units may need to be tested in isolation, using test drivers and stubs. In other cases, it may be more efficient to conduct unit testing on a collection of related units, such as an Ada package. The manager should select the level of formality and rigor that is most cost effective for the project.

Purpose — Unit testing verifies the logic, computations/functionality, and error handling of a unit.

Plan — Usually written by the unit developer, unit test plans are informal. Procedures for testing complex algorithms at the unit level are contained in the analytical test plan.

Participants — The unit developer generally tests the unit, unless the cleanroom method with its separate test team is used (see Reference 9).

Activities — The tester prepares test data and any necessary drivers or stubs. He/she then executes the test plan, verifying all logic paths, error conditions, and boundary conditions. Test results are reviewed for accuracy and completeness by the task leader or designated technical authority.

Monitoring — Use number of units planned versus number successfully unit tested to measure progress; track number of errors found to gauge software reliability.

INTEGRATION TESTING

Purpose — Integration testing verifies the internal integrity of a collection of logically related units (called a module) and checks the module's external interfaces with other modules, data files, external input and output, etc.

Plan — Although a formal test plan is generally not required, integration testing is more carefully controlled than unit testing.

Participants — Integration testing is usually performed by the members of the development team responsible for the modules being integrated.

Activities — During integration testing, the software is slowly built up by adding a few units at a time to a core of modules that have already been integrated. Integration may follow a **top-down** approach, in which lower level modules are added to the top-level driver level by level. Alternatively, an end-to-end functional path, or **thread**, may be constructed, to which other modules are then added.

Monitoring — Use number of units planned versus number successfully integrated to measure progress; track number of errors found to gauge software reliability.

BUILD/RELEASE TESTING

A **build** is a portion of a software system that satisfies, wholly or in part, a subset of the requirements. A build that is acceptance tested and subsequently delivered for operational use is called a **release**. Build/release testing is used when the size of the system dictates that it be implemented in multiple stages.

Purpose — Build testing verifies that the integrated software fulfills a predetermined subset of functional or operational system requirements.

Plan — The tests to be executed are defined in a build/release test plan**.** Build tests are often subsets of system tests (see Figure 4-7).

Participants — Build testing is generally performed and evaluated by members of the system test team.

Activities — The activities conducted during build testing are basically the same as those of system testing.

Monitoring — Use number of test cases identified versus number successfully tested to measure progress; formally track errors found to gauge reliability; track effort required to fix to predict maintainability.

SYSTEM TESTING

System testing verifies the full, end-to-end capabilities of the system. The system testing phase follows the implementation test phase; it begins after the last build of the system has been successfully completed.

Where high reliability software is required for a particular mission application (e.g., flight or significant real-time software), it is recommended that system testing be planned and performed by an independent verification and validation (IV&V) team. Experience within the SEL environment has found the use of IV&V adds between 5 and 15 percent to total project costs.

Purpose — System testing verifies that the full system satisfies its functional and operational requirements. The system must be demonstrated to be both functionally complete and robust before it can be turned over to acceptance testers.

Plan — The test and verification approach is specified in the system test plan (Figure 4-7). A system test plan may be developed based on an analytical test plan (designed to show how the computational accuracy of the system can be verified) or based on the acceptance test plan.

Participants — The system test team is composed of developers supported by one or more analysts and is led by a specialist in the developed application. In the flight dynamics environment, mission critical applications are tested by an independent team.

Activity — Test execution follows the pattern prescribed in the system test plan. Discrepancies between system requirements and the test results are identified and assigned to members of the development team for correction. Each change to the system is handled in accordance with established CM procedures. Regression tests are performed after repairs have been made to ensure that the changes have had no unintended side effects. System testing continues until no more errors are identified.

Monitoring — Use number of test cases identified versus number successfully tested to measure progress; formally track errors found to gauge reliability; track effort required to fix to predict maintainability.

ACCEPTANCE TESTING

Acceptance testing is begun after system testing has been successfully completed. Complete drafts of the user's guide and system description are provided to acceptance testers by the beginning of the acceptance test phase.

Purpose — Acceptance testing verifies that the system satisfies its requirements.

Plan — All acceptance tests executed are based on the acceptance test plan written by analysts prior to the start of the phase (see Figure 4-7).

Participants — Tests are executed by the acceptance test team supported by members of the development team. Testing may be observed by product assurance representatives and the user.

Activity — After preparations for testing are completed, the test team attempts to execute all tests in the plan, working around any errors they uncover. This ensures that major problems are discovered early in the phase. Only when execution of a load module (i.e., an executable image) is totally obstructed does testing cease until a new load module can be installed. Each new load module is regression tested to ensure that previously demonstrated capabilities have not been adversely affected by error corrections.

Monitoring — Use number of test cases identified versus number successfully tested to measure progress; track errors found to gauge reliability; track effort required to fix to predict maintainability.

TEST MANAGEMENT GUIDELINES

A summary of essential management guidelines on software testing is presented below. The observations about the planning and control of testing are derived from SEL experience.

Realize that testing is important — 30 percent of development effort in the flight dynamics environment is devoted to system and acceptance testing

Apply adequate resources

- Time — 35 percent of the time schedule
- Staff — experienced, well-trained in defect detection
- Computer — peak use in testing phases of FORTRAN projects (see Figure 3-2)

Plan for it early — as part of the software development/management plan

Plan for it explicitly — using formatted test plans (see Figure 4-7)

Test continually during the life cycle with five major types of testing (Reference 10) — **unit, integration, build/release, system,** and **acceptance**

Prepare for testing — use testability as a criterion for evaluating requirements statements, designs, and build/release plans

Apply testing aids (Reference 2)

- Requirements allocation matrices
- Decision tables and test summary tables
- Test library

Monitor testing costs (Reference 3) — collect data on

- Calendar time and staff effort spent testing and verifying software
- Cost of diagnosis — finding the defect
- Cost of repair — making all the necessary corrections to code and documentation

Measure testing progress

- Compare testing costs and number of defects with past projects
- Record defect detection rate as testing effort is applied
- Track number of tests identified, number executed, and number passed. The percentage of executed tests that fail should be nearly halved for each subsequent load module tested (see Table 5-1)

Table 5-1. Expected Percentage of Tests Executed That Pass

LOAD MODULE	AVERAGE PASS RATE	PASS RATE RANGE
Version 1	50%	35-70%
Version 2	77%	75-80%
Version 3	88%	85-90%
Version 4	99%	95-100%

CERTIFICATION

Broadly defined, certification is a statement attesting to something. For example, an individual may be charged with certifying that

- Coding standards were followed
- Code agrees with PDL
- CM procedures have been followed
- Specific test cases were run
- All contractual items have been delivered

Although there is considerable diversity in what is being certified, there are common aspects as well. Certification is a binary decision — either the materials or activities are certified or they are not. It is performed by individuals who can be objective about their certification assignment. This objectivity is a key reason for introducing certification into the software development process. Certification contributes to quality assurance by providing an independent check on development. Confidence in the final software product is enhanced if both the process and product are certified.

Essential management guidelines for certification are summarized below.

Determine the objective of the certification, e.g., to ensure that

- Design, code, or documentation is correct
- Standards, procedures, or guidelines are being followed
- System performance meets operational requirements

Define entry criteria — what materials must be submitted for certification?

- Establish procedures for obtaining documents or code that will be required
- Identify the individuals responsible for certification

Define exit criteria — certification is a binary decision. How will submitted materials be evaluated to make the certification decision?

Specify the certification procedure, document it, and follow it

More detailed recommendations depend on the object of certification. For example, in certifying intermediate products like designs, test plans, or unit code, the materials submitted for certification and the evaluation criteria will vary. Figure 5-1 shows the general guidelines applied to an example of unit design certification.

1. **Certification Objectives**:
   a. Ensure the design correctly provides the functionality required of the unit
   b. Check for conformance with standards and conventions regarding prolog and PDL
   c. Identify visible weaknesses in the design early so that defects can be repaired with minimum cost
   d. Encourage developers to thoroughly specify all unit interfaces — calling arguments, parameter specifications, etc.

2. **Entry Criteria** — the following materials must be submitted:
   a. Source listing of prolog and PDL
   b. Structure chart or object-oriented diagram of the subsystem or major component to which the unit belongs
   c. Design certification form, containing author's name, date submitted for certification, unit name, and subsystem name

3. **Exit Criteria** — some questions will be specific to the design methodology used. The following are more general questions, typically used to evaluate submitted materials and decide on certification:
   a. Do the prolog and PDL adhere to all prevailing standards and conventions?
   b. Are all necessary elements of the prolog complete, e.g., are all data elements described?
   c. Does the PDL describe a valid process for providing the function assigned to the unit?
   d. Is it clear from the PDL when the unit output will be generated?
   e. Is the dependency clear between each input parameter or external reference and the processing described in the PDL?
   f. Does the PDL define enough error detection logic?
   g. Does the PDL account for the upper and lower bounds of unit input?

4. **Certification Procedure** — recommended steps for the certification:
   a. Meet with the development team leader to establish the position of unit design certification in the project's life cycle; all units must have their design certified before they are implemented
   b. Issue written descriptions of entry criteria, with examples of the required form for submitted materials
   c. Prepare a unit design certification checklist, based on exit criteria, to record evaluation results
   d. Document the procedure for obtaining materials, completing the certification checklist, and presenting results to the development team
   e. Implement the procedure, retaining certification results in the project library

Figure 5-1. Example of Unit Design Certification

SECTION 6 — METRICS AND KEY MANAGEMENT AIDS

Effective software project management and control depends on an accurate assessment of a project's health at any point in the life cycle. This assessment must be based on up-to-date metrics that reflect the status of the project, both in relation to the project plan and in comparison to models of expected performance drawn from historical experience with similar projects.

This section presents useful metrics for project evaluation and control and discusses several tools designed to aid managers in performing these critical functions.

METRICS

Software metrics/measures can provide the manager with key indicators of project performance, stability, and quality. Both objective and subjective measures are important to consider when assessing the current state of a project. **Objective data** consist of actual counts of items (e.g., staff-hours, SLOC, components, test items, units coded, changes, errors, etc.) that can be independently verified. They are usually collected through a formal data collection process. **Subjective data** are based on an individual's or a group's feeling or understanding of a certain characteristic or condition (e.g., level of difficulty of the problem, degree of new technology involved, stability of the requirements, etc.). Together these data serve as a system of checks and balances throughout the project. The wise manager depends on both objective and subjective data to get an accurate picture of project health. Subjective data provide critical information for interpreting and validating the objective data, while the objective data provide true counts that may cause the manager to question his subjective understanding and investigate further.

Because collecting, maintaining, and reporting metric data can be a significant undertaking, each data item must serve a well-defined purpose. The project software development plan should define which data will be collected and how each data item will be used. To achieve the maximum benefit, metric data must be accurate, current, and accessible to the manager.

The availability of project metrics will be of no or little value unless the manager also has access to models or metrics that represent what should be expected. This information is normally in the mind of the experienced software manager. Ideally, such historical data and experience should also be stored in an "organizational memory" (data base) accessible to new managers. Using information extracted from such a data base, managers can gauge whether measurement trends in the current project differ from similar past projects and from the expected models for the local environment. The costs and benefits of such a data base are further discussed in References 3 and 11, respectively.

The SEL project histories data base holds key characteristics and performance models of software development in the SEL environment, as well as three classes of data for each past project: cost, process, and product data. **Cost data** are confined to measures of effort. The use of effort data removes the effects of labor rates and hardware costs, allowing the manager to focus on the more accurately modeled costs of software development and system engineering. **Process data** include information about the project (such as methodology, tools, and techniques used) and information about personnel experience and training. **Product data** include size, change, and error information and the results of statistical analyses of the delivered code.

Figure 6-1 suggests the possibilities for useful comparison when a project histories data base is available. Models based on completed projects help the manager initiate and revise current plans and estimates. As performance data are gathered for a new project, the manager can compare these values with those for related projects in the data base.

The comparisons in Figure 6-1 should be viewed collectively as one component of a feedback and control system. Comparisons lead to revisions in development plans. To execute the revised plans, the manager makes changes in the development process, which result in adjusted measures for the next round of comparisons.

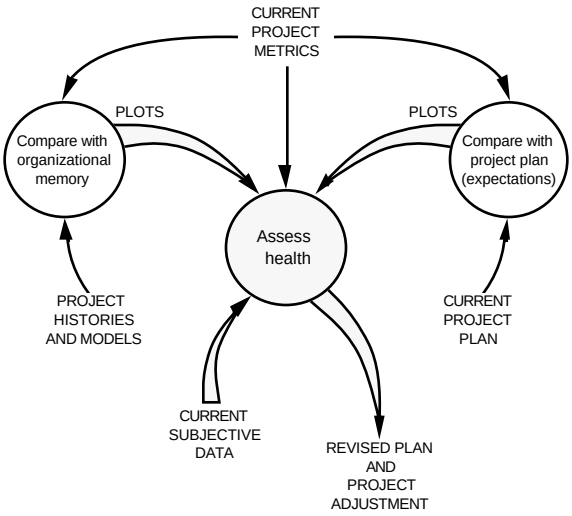


Figure 6-1. Management Through Measurement

MANAGEMENT METRICS AND THEIR USE

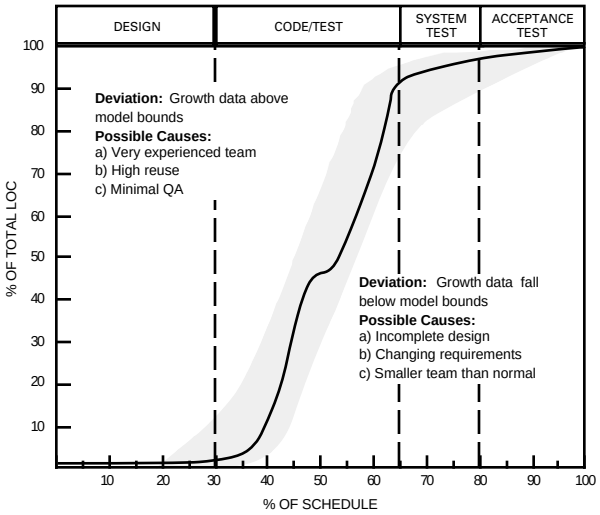
An endless list of metrics can be proposed for management use, ranging from high-level effort and software size measures to detailed requirements measures and personnel information. Quality, not quantity, should be the guiding factor in selecting metrics. It is best to choose a small, meaningful set of metrics that have solid baselines in the local environment.

In the SEL, eight key metrics contribute to the successful management of software development projects: 1) **source code growth rate**, 2) **effort data**, 3) **system size estimates**, 4) **computer usage**, 5) **error rates**, 6) **reported/corrected software discrepancies**, 7) **software change rate**, and 8) **development activity status data**. Managers analyze the metrics individually and in sets to get an accurate reading of the health of their projects with relation to cost, schedule, and quality. Many of these metrics provide critical insight into the stability of a project — insight that is lacking in standard performance measurement systems.

The following pages describe these eight key software management metrics. The models presented have been developed and refined based on the software heritage that is recorded in the SEL data base. In each case, a real project example is presented that demonstrates the use of the metric.

SOURCE CODE GROWTH RATE – 1

- *Strong progress indicator during implementation*
- *Key stability indicator during testing phases*
- *Tracks amount of code (SLOC) in configured library*



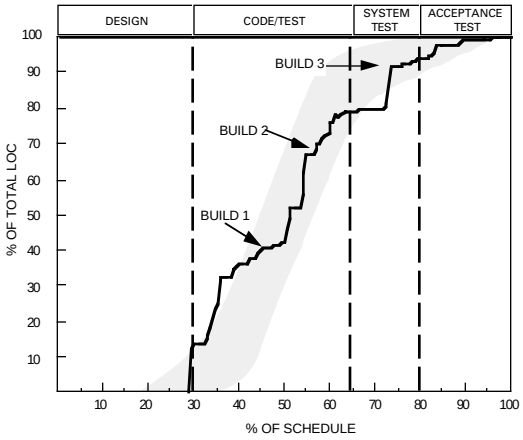
NOTE: Overall trend is the same for both Ada and FORTRAN systems. Ada systems show more growth in the design phase as compiled PDL is produced.

Figure 6-2. SEL Software Growth Profile

The growth of source code in the configured library closely reflects requirements completeness and the software development process. In the SEL environment, periods of sharp growth in SLOC are separated by periods of more moderate growth (Figure 6-2). This is a reflection of the SEL practice of implementing systems in builds. The model shows that, in response to requirements changes, 10 percent of the code is typically produced after the start of system testing.

A deviation from the growth model simply emphasizes that the project is doing something differently. For example, a project that is reusing a large amount of existing code may show a sharp jump early in the code phase when reused code is moved into the configured library.

Figure 6-3 shows an example from the SEL environment, where code growth occurs in a step-wise fashion, reflecting builds. The Gamma Ray Observatory (GRO) AGSS (250 KSLOC), developed from 1985 to 1989, was impacted by the shuttle accident. Beginning with the implementation phase, the schedule was stretched over 3 years and the staff reduced accordingly.



Explanation: Build 1 shows early rapid growth due to a high level of code reuse. Build 3 shows a long delay before completing code in the middle of the system test phase. This was due to major specification problems in two of the three subsystems involved.

Figure 6-3. Example of Code Growth — GRO AGSS

EFFORT DATA – 2

- *Staffing profiles should reflect the environment and project type*
- *Effort is a key indicator of progress and quality*
- *Effort data are critical replanning aids*

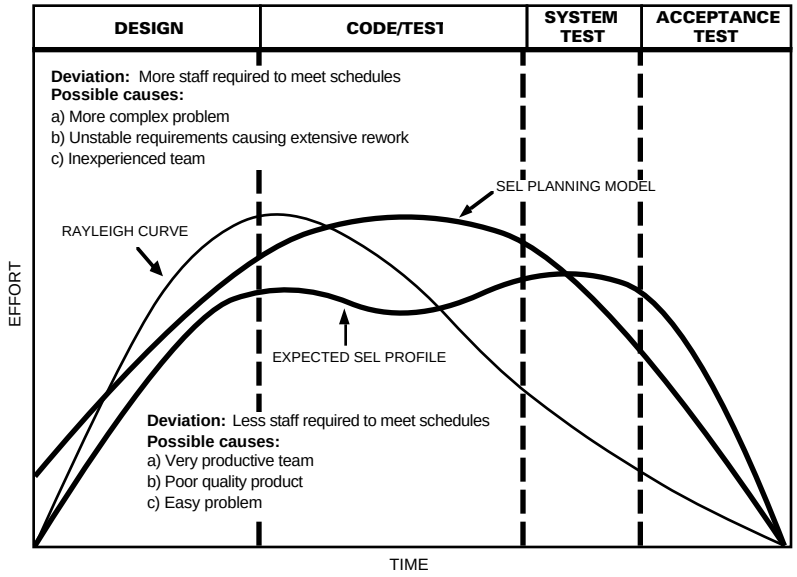
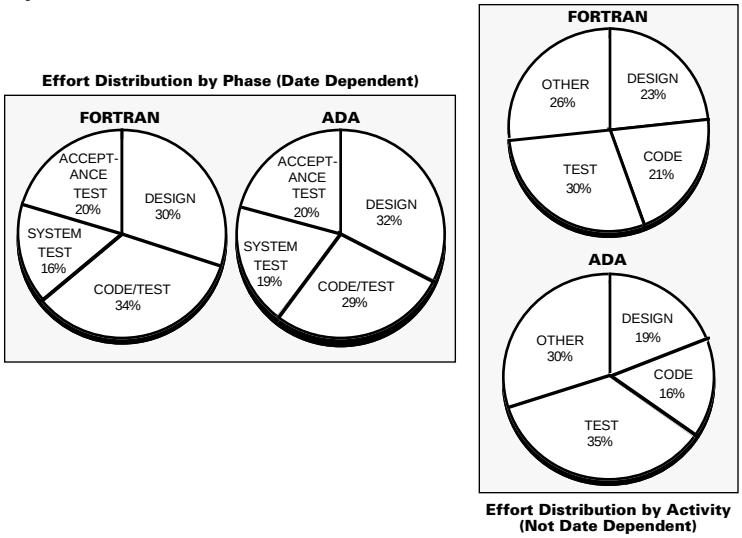


Figure 6-4. SEL Staffing Profile Model

The typical staffing profile closely reflects the nature of the project environment and the type of problem being solved. In the SEL environment, where a substantial portion of requirements details are not known until mid-implementation, managers plan for a parabolic staffing profile instead of the traditional, widely used Rayleigh curve (see Figure 6-4). However, once a project is underway, they expect to see the doubly convex curve shown above. The cause of this trend is not well-understood, but it occurs repeatedly on flight dynamics projects in this environment and, therefore, is the SEL model.

Another important profile is the expected effort distribution among software development phases and among software development activities. The SEL effort distribution models (Figure 6-5) show some differences between FORTRAN and Ada projects.



NOTE: The projects sampled for this figure were selected for the purpose of comparing FORTRAN to Ada and differ from those used to generate Tables 3-1 and 3-2.

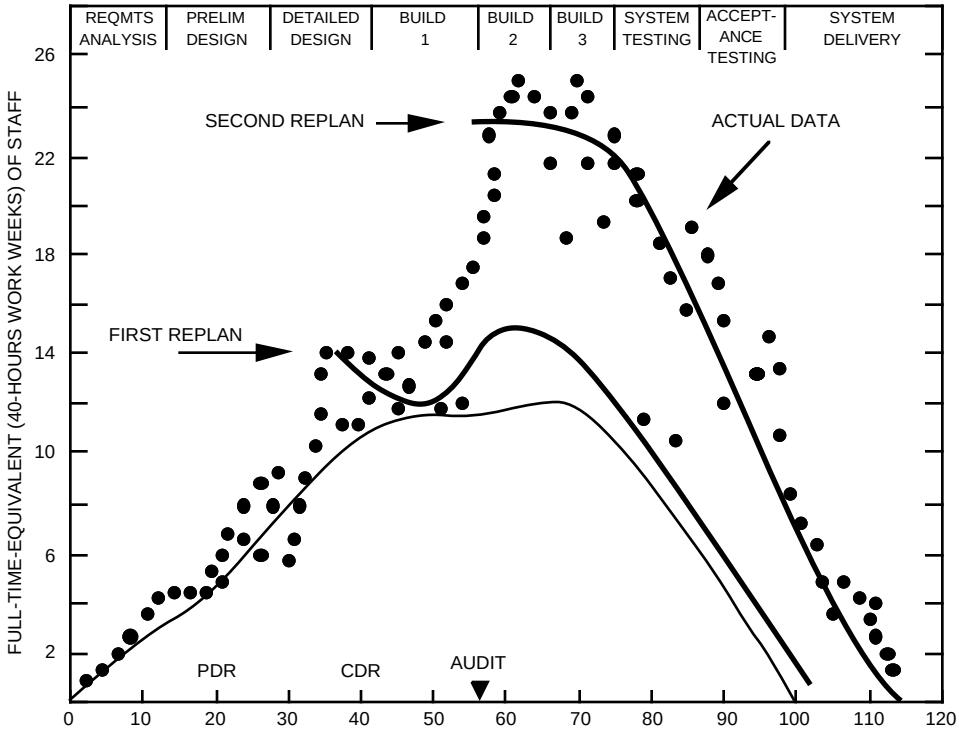
Figure 6-5. SEL Effort Distribution Models

The SEL has found these metrics to be key factors in characterizing their environment. They are also used as a yardstick for assessing the impact of new technology.

Utilizing the expected effort distributions and staffing profile, a manager can predict the total cost and schedule based on effort spent to date. If more effort is required to complete the design of a system than was planned, it is likely that the remaining phases will require proportionately more effort as well. After investigating why the deviation has occurred, the manager can make an informed choice as to whether staff or schedule must be increased and can plan accordingly.

Deviations in effort expenditure can also raise quality flags. If all milestones are being met on an understaffed project, the team may appear to be highly productive, but product quality may be suffering. In this case, the manager should not automatically reduce future effort predictions but, based on an audit of the design and code, may need to add staff to compensate for work not thoroughly completed in earlier phases.

Figure 6-6 presents an example of the use of metrics data in both planning and monitoring a project. The Earth Radiation Budget Satellite (ERBS) AGSS (160K SLOC), developed during the 1982-1984 timeframe, is considered to be a highly successful project. Effort data were a key factor in management's detection and timely correction of several problems that would have seriously jeopardized project progress.

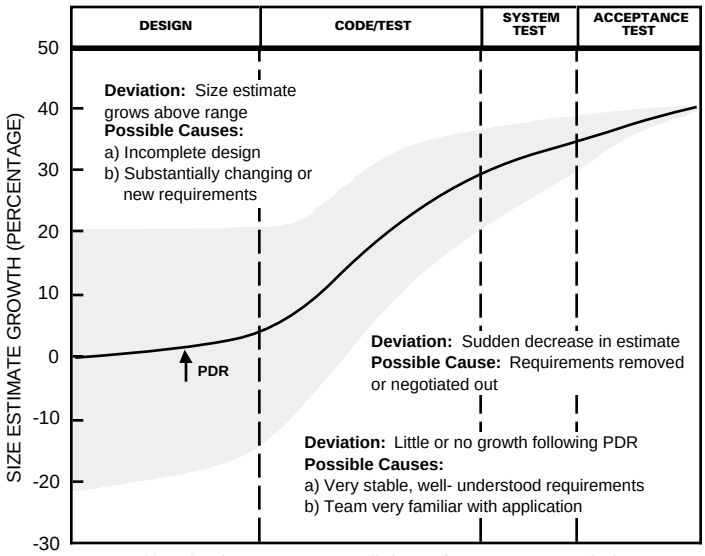


Explanation: The original staffing plan was based on an underestimate of the system size. Toward the end of the design phase, 40% more effort was required on a regular basis. This was one of many indicators that the system had grown, and the project was replanned accordingly. However, effort continued to grow when the second plan called for it to level off and decline. When it was clear that still more staff would be required to maintain progress, an audit was conducted. The audit revealed that the project was plagued with an unusually large number of unresolved TBDs and requirements changes that were causing an excessive amount of rework and that — as part of the corrective action — another replan was necessary.

Figure 6-6. Effort Data Example — ERBS AGSS

SYSTEM SIZE ESTIMATES – 3

- *Tracks change in estimates of final system size (in SLOC)*
- *Is a key indicator of system stability*
- *Size will typically be up to 40% larger than PDR estimates*
- *Estimates should be made monthly by project manager*
- *Metric used must be consistent — either executable, total, or noncomment lines*



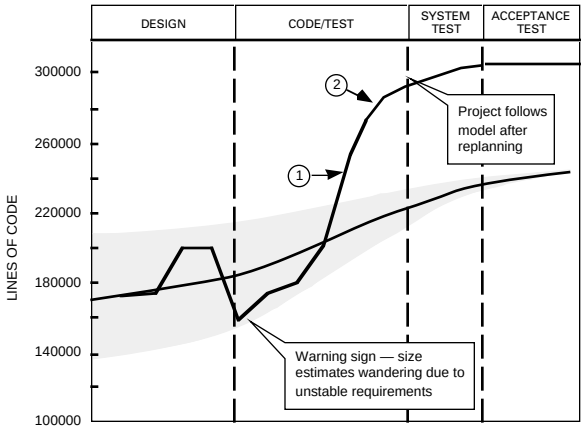
NOTE: Although Ada systems are usually larger than FORTRAN equivalents, no appreciable differences have been noted in the growth percentage.

Figure 6-7. SEL Size Estimates Model

The growth of software size estimates should reflect requirements stability and completeness within the environment. The profile must either be based on heritage or on a measure of requirements clarity and completeness.

In the SEL environment, a large number of TBDs in the requirements and specifications, combined with a substantial number of requirements changes, typically cause a system to grow up to 40 percent larger than is estimated at the time of PDR. As the details of the unknown portions of the system become clear, the size estimate grows more rapidly. The range of accepted growth narrows as the system is clearly defined (see Figure 6-7).

In the example shown in Figure 6-8, investigation revealed that the project requirements were growing substantially and that additional funding was needed to complete the work.



Symptom: System size exceeds 40 percent growth threshold midway through implementation (1).

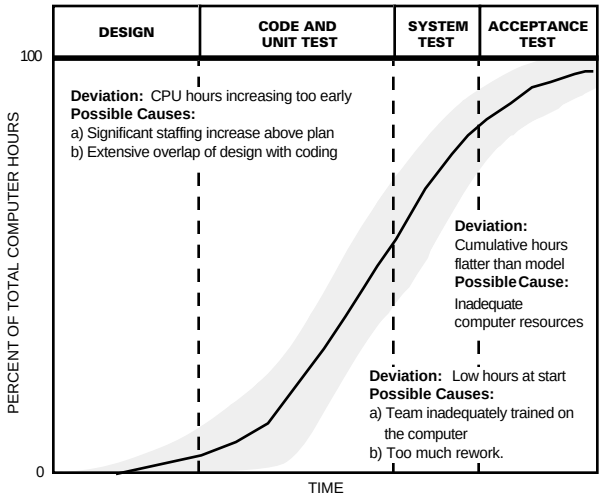
Cause: Excessive requirements changes; entirely new capabilities (subsystems) added; and ineffective change control mechanism.

Corrective Actions: Review cost for requirements submitted since CDR on a case-by-case basis. Enforce change control procedures on future specification modifications. Request more budget, and replan based on resulting system size (2).

Figure 6-8. Sample Size Estimates — UARS AGSS

COMPUTER USAGE – 4

- *CPU is a key progress indicator for design and implementation*
- *Use of CPU should reflect environment and process phase*
- *Either CPU time or number of runs may be used*



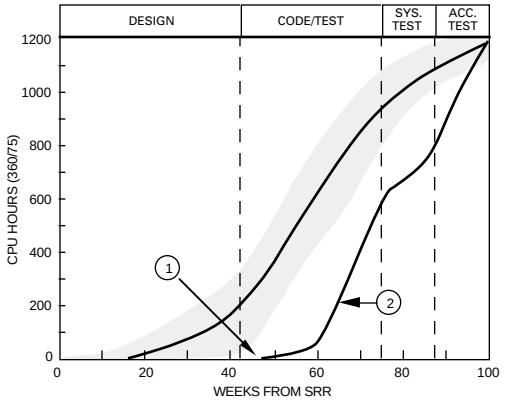
NOTE: Ada systems require more CPU time throughout the development lifecycle. However, the overall trend (expressed as percent of the total) is the same for similar FORTRAN and Ada systems.

Figure 6-9. SEL Computer Usage Model

The use of CPU is directly related to the particular process being applied, but trends have been found to be heavily environment dependent. The profile must either be based on heritage or a specific project plan. Use of a development methodology that calls for extensive desk work, such as the cleanroom methodology (Reference 9), will inevitably create significant deviations.

On a typical SEL flight dynamics project, a small amount of CPU time is used during the design phase for prototyping and entering PDL (more time is used in Ada systems for which PDL is compiled). The steep upward trend early in the implementation phase reflects an increase in online development activities (see Figure 6-9). System testing is CPU-intensive, continuing the trend. Further but slower increases during acceptance testing are due to extensive numerical testing and analysis.

Figure 6-10 is an example of CPU metrics taken from the ERBS AGSS, developed from 1982 to 1984 (160 KSLOC). This project deviated from the SEL model and raised a red flag. In this case, investigation showed that the project was being adversely affected by unstable requirements.



Symptom: Computer usage zero midway through implementation (1).

Cause: Project doing redesign in response to excessive requirements changes instead of implementation.

Corrective Action: Replan project based on new scope of work (2).

Figure 6-10. Example of Computer Usage — ERBS AGSS

ERROR RATES – 5

- *Track errors vs. total estimated size of project in developed SLOC*
- *Error rates should continually decrease in subsequent phases. The SEL has found the "halving" model reasonable, in which rates are cut by 50% each phase*
- *Accounting for differences in coding style, rates are similar for FORTRAN and Ada, although classes of errors differ*

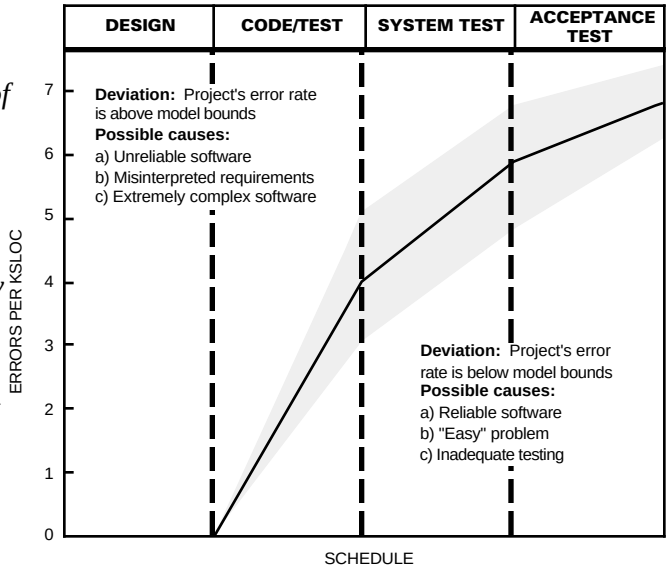
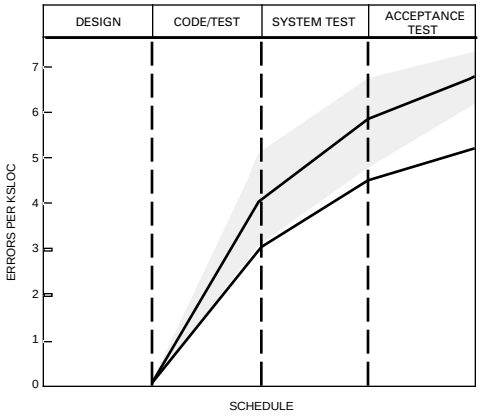


Figure 6-11. SEL Error Rate Model

There are two types of information in the error rate model shown in Figure 6-11. The first consists of the absolute error rates expected in each phase. The rates shown here are based on projects from the mid-1980s. The SEL expects about four errors per thousand SLOC during implementation, two during system test, and one during acceptance testing. Analysis of more recent projects indicates that error rates are declining as the software development process and technology improve.

The second piece of information is that error detection rates reduce by 50 percent in each subsequent phase. This trend seems to be independent of the actual values of the error rates. It is still true in recent projects where overall error rates are declining. However, if the error rate is low and the detection rate does not decline from phase to phase, inadequate testing and a less reliable system are likely.

Figure 6-12 is an example from the Cosmic Background Explorer (COBE) AGSS software developed from 1987 to 1988 (175 KSLOC).



Symptom: Lower error rate and lower error detection rate.

Cause: Early indication of high quality. Smooth progress observed in uncovering errors, even between phases (well-planned testing).

Result: Proved to be one of the highest quality systems produced in this environment.

Figure 6-12. Sample Error Rates — COBE AGSS

REPORTED/CORRECTED SOFTWARE DISCREPANCIES – 6

- *Key information is in the slope of the "Open Reports" curve*
- *Expect sharper error increases at start of each phase*
- *Trends (rates) in each of the three curves provide information*
- *Model is similar for both FORTRAN and Ada projects*

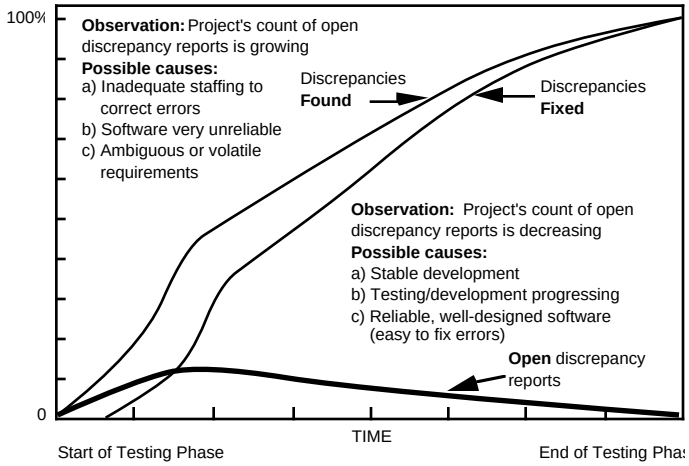
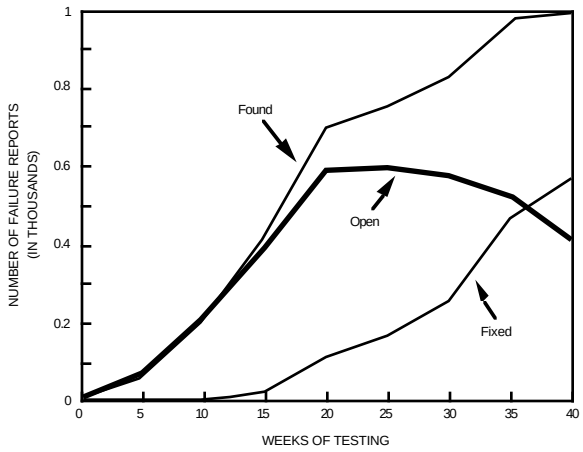


Figure 6-13. SEL Software Discrepancy Status Model

By consistently recording reported vs. fixed discrepancies, the manager will gain insight into software reliability, progress in attaining test completion, staffing weaknesses, and testing quality. The "open reports" should decline as testing progresses unless there are inadequate staff correcting pro-blems or the software is exceptionally "buggy". The point at which the "open" and "fixed" curves intersect is the point at which defects become corrected faster than they are reported. At this time, the manager can more confidently predict the completion of the testing phase (see Figure 6-13).

This error data — combined with test executions and pass rates — will enable the manager to predict quality and completion dates. When the number of errors found is lower than expected, while the test rate is at or above normal, the software is of high quality.

The example shown in Figure 6-14 is from the Trajectory Computation and Orbital Products System (TCOPS) developed from 1983 to 1987. The total size of this system was 1.2 million SLOC.



Symptom: Early in testing, errors were not getting corrected (first 15 weeks).

Cause: Lower quality software. Errors were not found during system testing.

Corrective Actions: Staffing was increased at week 20 to help address open errors.

Results: System attained stability at week 35, with errors being corrected faster than they were being reported.

Figure 6-14. Example of Discrepancy Tracking — TCOPS

RATE OF SOFTWARE CHANGE – 7

- *Reported changes include errors*
- *Change rate is a key stability indicator*
- *Both absolute rate and weekly increments are significant*

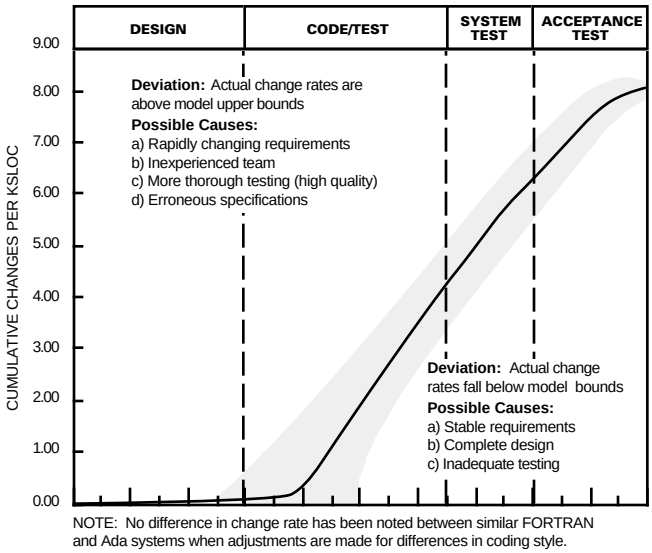
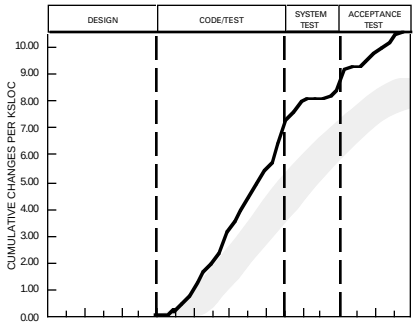


Figure 6-15. SEL Change Rate Model

The rate at which the software is changing strongly reflects the software development process and stability of project requirements, so any model used for comparative analysis must be based on a solid understanding of the environment. Two key pieces of information are shown in the model: (a) the absolute value of the change rate and (b) the week-to-week trend.

In the SEL environment, the expected change rate has been determined through past project measurement. The model (Figure 6-15) reflects a steady, even growth of software changes from mid-implementation through acceptance testing. Exaggerated flat spots (periods without change) or a large jump (many changes made at the same time) in the data should raise flags. Some deviations of this nature may be normal (e.g., during the testing phase, code CM procedures often cause changes to be held and recorded as a group). However, any deviation is a warning sign that should spur investigation.

Figure 6-16 presents an example from the SEL environment of a project that experienced a higher than normal change rate. The specifications for the Geostationary Operational Environmental Satellite (GOES) AGSS (129 KSLOC), developed from 1987 to 1989, were unusually problematic. Many changes to the requirements were made throughout the project, even after implementation had begun. Early recognition of the change rate allowed managers to compensate for this by tightening CM procedures.



Symptom: Change rate higher than normal range beginning midway through implementation.

Cause: Unusually high number of specification errors and requirements changes.

Corrective Action: Strongly enforced CM procedures to deal with changes.

Result: High-quality project delivered on schedule.

Figure 6-16. Change Rate Example — GOES AGSS

DEVELOPMENT ACTIVITY STATUS DATA – 8

- *Key progress indicator*
- *Indirect software quality indicator*
- *Model must reflect development methodology used*
- *Monitor only major activities*

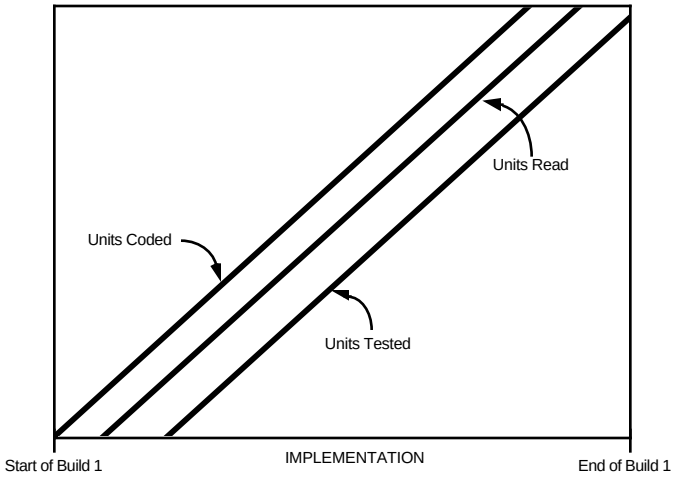
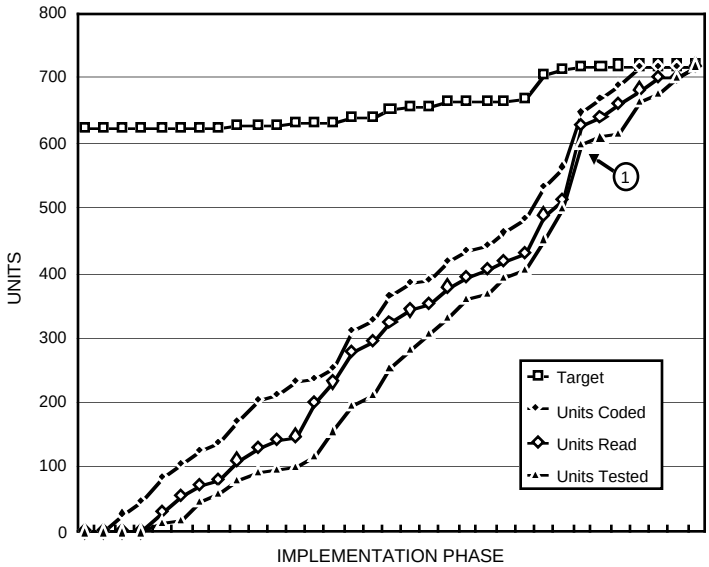


Figure 6-17. SEL Development Status Model for a Single Build

Development status measures provide insight into the progress of individual development activities that comprise a particular phase. These activities should represent the major sequential steps required to complete development of software units. Development status measures are valuable in design, implementation, and testing phases. In the SEL environment, managers track these measures individually to see that all activities are progressing smoothly and in parallel. Figure 6-17 presents an idealistic model for the activities required to implement a software build.

Figure 6-18 presents an example from the SEL environment, showing development status data for the entire implementation phase. The GOES Dynamics Simulator in Ada (GOADA, 171 KSLOC) was developed between 1987 and 1990. The project finished code and unit testing nearly on schedule. When severe problems were encountered during system integration and testing, it was found that insufficient unit testing had resulted in poor quality software.



Symptom: Miracle finish (1) — code reading and unit testing activities catch up to coding near deadline, when a 3-4 week lag was standard earlier in the phase.

Cause: Some crucial testing information was not available; short cuts were taken in code reading and unit testing to meet schedules.

Result: Project entered the system testing phase with poor quality software. To bring the software up to standard, the system test phase took 100% longer than expected.

Figure 6-18. Development Profile Example — GOADA

ADDITIONAL MANAGEMENT METRICS

As mentioned earlier, each environment must determine which metrics and indicators are most useful for supporting the management process. Obviously, the eight SEL metrics just described are not universally applicable. In addition, other measures may be used for particular projects by managers in environments with unique characteristics. Although numerous additional metrics are defined in the literature, only those measures that have been used successfully as management aids in the SEL are described below (Table 6-1).

None of these recommended measures are useful without some baseline or expectation of what the values may be in a particular environment. If no empirical data exist, an organization may propose baselines derived from subjective estimates. However, as soon as a metrics program is instituted, the subjective baselines must be substantiated or refined using objective data.

Table 6-1. SEL Recommended Metrics

METRIC	SOURCE	FREQUENCY (COLLECT/ANALYZE)	TYPICALLY USED IN DETERMINING...
Changes (to source)	Tool	Weekly/weekly	Quality of configuration control, stability of specifications/design
Changes (to specifications)	CM	By event/biweekly	Quality of specifications, the need to replan
Changes (classes of)	Developers	By event/monthly	"Gold plating", design instability, specifications volatility
Computer usage	Tool	Biweekly/biweekly	Progress, design instabilities, process control
Discrepancies (reported/ open)	Testers and developers	By event/biweekly	Areas of staffing needs, reliability of software, schedules
Effort (total)	Time accounting	Weekly/weekly	Quality of planning/managing
Effort (per activity)	Developers and managers	Weekly/monthly	Schedules, the need to replan
Effort (to repair/to change)	Developers	Weekly/monthly	Quality of design, cost of future maintenance
Errors (per inspection)	Developers	By event/monthly	Quality of software, lack of desk work
Errors (classes of)	Developers	By event/monthly	Specific design problems
Errors (total)	Developers	By event/monthly	Software reliability, cost of future maintenance
Size (modules planned/ designed/inspected/ coded)	Managers	Biweekly/biweekly	Progress
Size (manager's estimate of total)	Managers	Monthly/monthly	Stability of specifications, the need to replan
Size (source growth)	Tool	Weekly/weekly	Quality of process, design completeness/quality
TBDs (specifications/ design)	Managers	Biweekly/biweekly	Level of management control
Tests (planned/ executed/ passed)	Testers	Weekly/weekly	Completion schedules, progress

DATA COLLECTION

To produce the metrics described, accurate data must be extracted from the development project. It is important to determine which management measures are going to be utilized during the development process so that effort is not expended in collecting extraneous data.

Table 6-1 includes the recommended frequency for which data used for the management measures should be collected. It also contains the recommended source of each of the required metrics. Once again, it should be noted that most projects would probably use only a subset of the measures listed in the table. The cost in project overhead to define, collect, and utilize the metrics described is relatively small, providing that only those metrics to be used in management activities are actually collected.

Normally, three categories of cost are associated with a "metrics" program:

- Overhead to a development project (filling out forms)
- Cost of processing the data (QA, data entry, storing, filing)
- Cost of analyzing the data (research and "process improvement" programs)

The overhead to the software development task itself for providing the listed metrics is minimal — well under 0.5% of the project cost — while the data processing cost for the management metrics program should be no more than 2% of the cost of the project in question. This includes data entry, data processing, generating summary output, and routine QA. The third category (analyzing data) is minimal for routine use in software development efforts and should be considered a normal managerial responsibility. The analysis function can be much more extensive in environments that are involved with a full "process improvement" and/or software engineering research program. In these cases, analysis costs could run as high as 10 to 20 percent of the total development effort.

AUTOMATING METRICS ANALYSIS (THE "SOFTWARE MANAGEMENT ENVIRONMENT")

As the corporate history of an environment grows and as the characteristics of the software process are better understood through the collection and application of metrics, an organization should evolve toward automating the structure, representation, and even analysis of these measures. The SEL has built such a tool to aid in the use of relevant metrics toward improved management awareness.

The Software Management Environment (SME, Reference 12) is an integrated set of software tools designed to assist a manager in monitoring, analyzing, and controlling an ongoing software project. The major functions of the SME include the ability to track software project parameters; to **compare** these factors to past projects; to **analyze** the differences between the current project's development patterns and the expected development pattern within the environment; to **predict** characteristics such as milestones, cost, and reliability; and to **assess** the overall quality of the project's development process. To provide these functions, the tool examines available development data from the project of interest including manpower, software changes, computer utilization, and completed milestones.

Figure 6-19 depicts the architecture and typical uses of an automated tool such as SME. The basis for the models and information available to such a tool must come from the collection of data within

the development environment and should result in such summary information as effort distribution in the life cycle, relationship equations, and the impact that varying technologies have on the development process. Examples are shown in Figure 6-20.

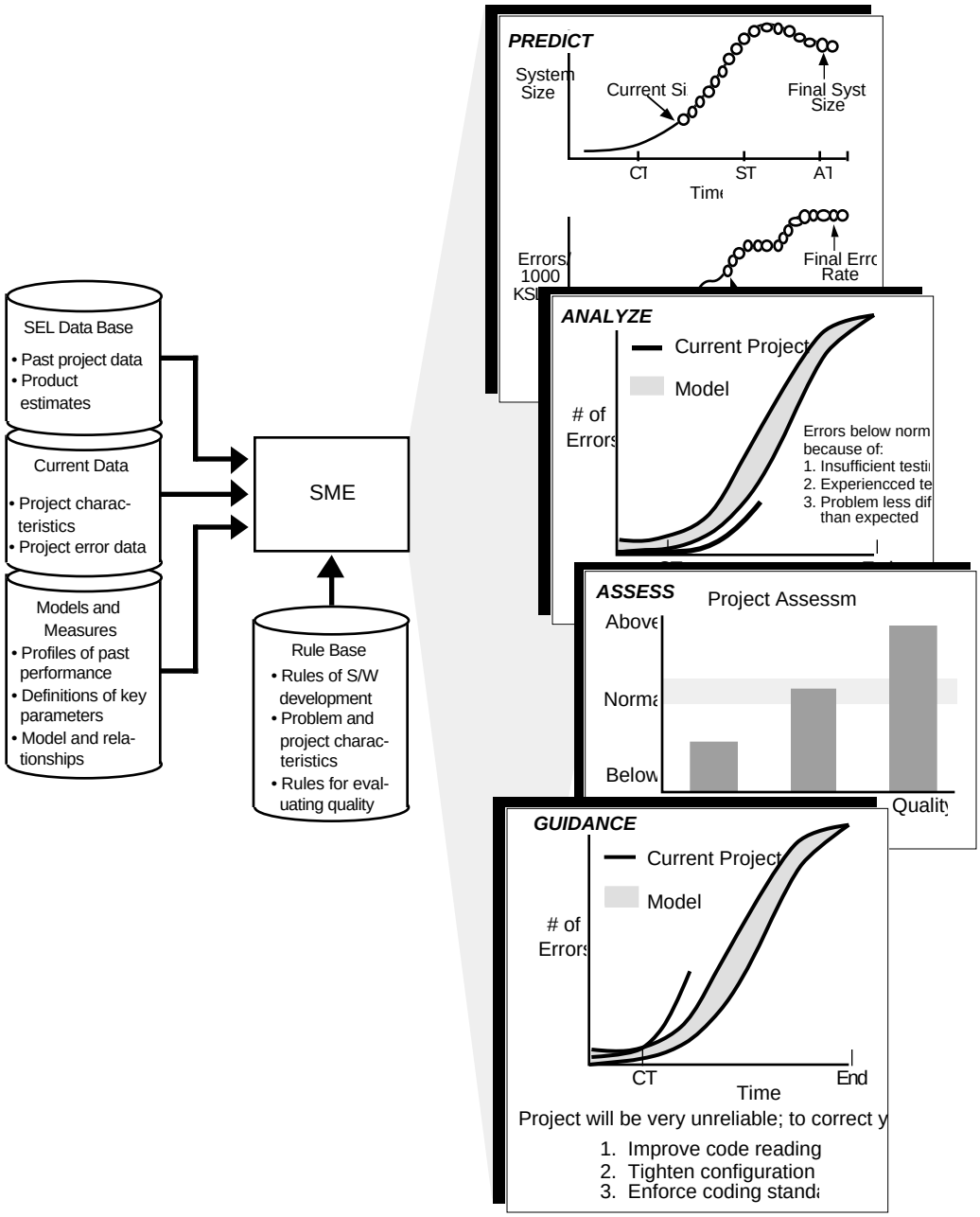


Figure 6-19. Example SME Output

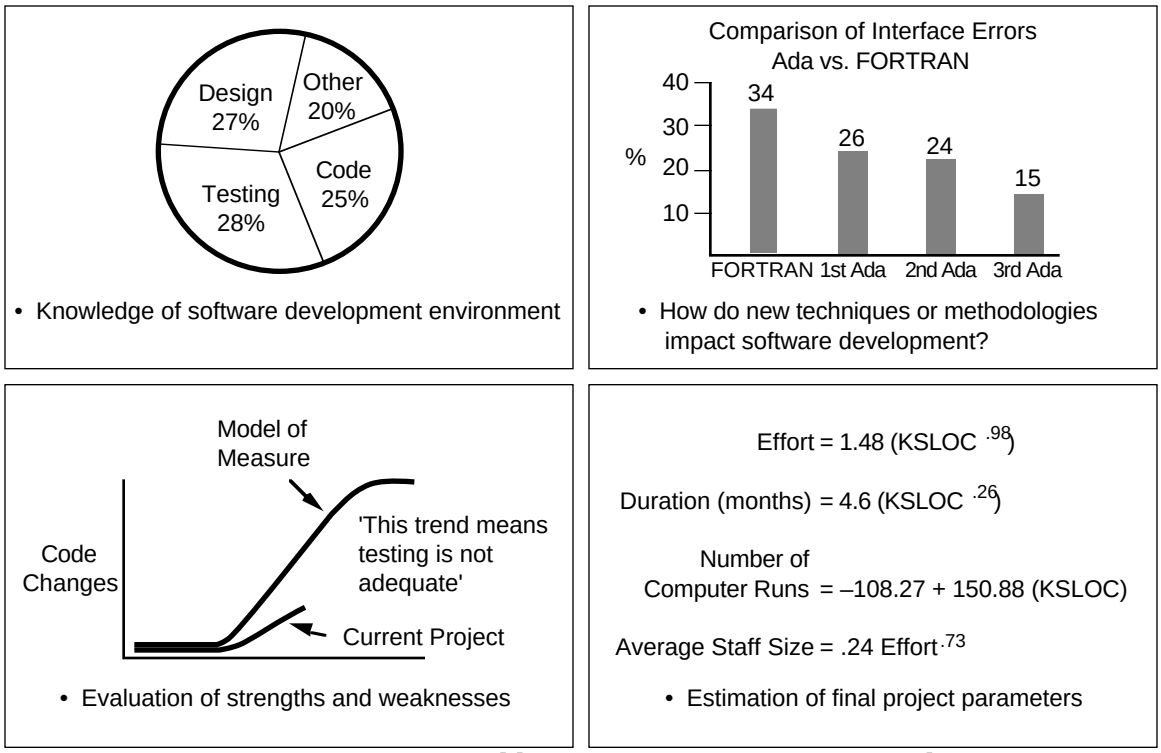


Figure 6-20. Build Corporate Memory Into a Tool

GENERAL INDICATORS OF PROJECT STATUS

The metrics described thus far function as objective yardsticks against which the manager can gauge project progress and quality. The following is a list of general characteristics — some subjective — that supplement these metrics as indicators of true project condition.

Frequency of schedule/milestone changes
Frequency and magnitude of changes should be decreasing throughout the development process.

Consistency in organizational structure compared to original plans
Minor adjustments to the organization of the project team are expected, but major changes indicate problems.

Fluctuation in project staff level and system size estimates
Fluctuations should be within uncertainty limits that become narrower as project development evolves.

Ease of access to information on project status, schedules, and plans
Rapid responses to questions about project status and schedules reflect well on the quality of the software development plan.

Number of overtime hours required or planned to attain certain objectives
Relying on overtime hours may indicate problems with the staff's qualifications or the team leadership.

Level of detail understood and controlled by the project manager and project leader
Managers' responses to questions about development progress indicate the degree of control exercised by leadership.

Discrepancies in staff level and workload
Major differences between planned workload and actual workload may indicate lack of understanding.

Discrepancies in computer usage
A decrease or slow start in using the computer may indicate incomplete design.

WARNING SIGNALS AND CORRECTIVE ACTIONS

When a project is in trouble, the manager must take immediate corrective measures to move it back on a successful course. The following lists of **warning signals** and corresponding **corrective actions** itemize many of the common problems identified by the SEL.

Problems With Requirements and Specifications

Number of TBD requirements higher than norm or not declining
If critical specifications are missing, design of the affected portions of the system should not proceed until the information is obtained. In noncritical cases, development may continue despite the incompleteness. Assess the effect of missing requirements/ specifications and determine whether relatively safe assumptions about the missing information can be made. Before starting the next phase, prepare a risk management plan. For all TBD specifications, assign due dates for resolution of TBDs and notify higher management if schedules are not met.

Number of requirements questions submitted vs. questions answered is high and increasing
Indicates inconsistent or confusing specifications. Difficulties become compounded if development is permitted to continue. Stop development activity and resolve inconsistency or confusion in consultation with the user organization. Negotiate a reduction in the scope of the system by defining an understandable subset of the original system. Document all assumptions about requirements in the functional specification.

High number of specification modifications received vs. number completed
If major changes or additions to requirements are unavoidable, the design of the affected portion of the system must be postponed. Split development into two releases, with the late specifications included in the second release. Hold a separate CDR for the second release.

Problems With System Design

Actual number of components designed is fewer than estimated at a particular point in the detailed design phase
Lack of design growth may be due to poor direction from the team leader, inexperienced staff, use of new technology, or changing requirements. Determine the cause of the slow growth. Based on the cause, either replace junior personnel with senior personnel, provide training, decrease staff size to a manageable level, set up a prototyping effort to improve technical understanding, or decrease the scope of the system.

Problems With Implementation

Actual number of units coded, tested, and integrated is fewer than those estimated at a particular point in the implementation phase

Lack of code growth may be due to poor direction from the team leader, inexperienced staff, changing requirements, or incomplete design. Determine the cause of the slow growth. Based on the cause, either replace junior personnel with senior personnel, stop staff growth, or hold changes and complete implementation of a build first.

Number of completed units increases dramatically prior to the scheduled end of a build or release (the "miracle finish")

Indicates that code reading and/or unit testing were inadequately performed, and many coding errors have not been found. Reschedule the effort so that code reading is performed properly; otherwise, substantially more time will be consumed during system testing in isolating and repairing errors.

Problems With System or Acceptance Testing

Testing phase was significantly compressed

Testing may not have been as complete or as thorough as necessary. Review test plan and results closely; schedule additional testing if indicated.

The number of errors found during testing is below the norm

Test results may have received inadequate analysis. Use personnel experienced in the application to review test results and determine their correctness. Rerun tests as necessary.

Problems With System Configuration

More than one person controls the configuration

Sharing of configuration control responsibilities can lead to wasted effort and the use of wrong versions for testing. Select one person as the project librarian, who will organize configured libraries, implement changes to configured components, and issue documentation updates about the system. Component changes must be authorized by the technical leader responsible for QA.

"Corrected" errors reappear

The corrected version may not have been used because more than one person controlled the configuration, or the staff was not aware of the ripple effect of other changes that should have been made when the original error was corrected. Consolidate configuration control responsibility in one person. Assign more senior staff to analyze the effect of error corrections and other changes.

Problems With Development Schedules

Continual schedule slippage

Staff ability may have been misjudged or the staff needs firmer direction. Bring in senior-level personnel experienced in the application to direct junior-level personnel and provide on-the-job training. Decrease the scope of the system.

Development activity is uneven and ragged; effort drops dramatically immediately after a milestone is reached

Personnel have been assigned to work part-time on too many projects. Staff will tend to concentrate on a single project at a time, sometimes to the detriment of other project schedules. Reassign personnel, preferably to one project, but never to more than two at a time.

Personnel turnover threatens to disrupt development schedule

The effect of turnover is not directly proportional to the number of staff involved. For each key person who leaves a project, two experienced personnel should be added. A junior project member should be replaced by a person at least one level higher in experience. Only in this way can a manager balance the effects on the schedule of the training and familiarization time new staff will require.

Capabilities originally planned for one time period are moved to a later time period

If a corresponding move of later capabilities to an earlier time period has not been made, the danger is that the development team will not be able to handle the additional work in the later period. Obtain justification for the change with detailed schedule information for the new and old plans. If the shift of capabilities is extensive, stop development activity until the development/management plan can be revised, then proceed.

Change or decrease in planned use of methods or procedures occurs

The methods or procedures had some use or expected benefit or they would not have been included in the development plan. Obtain justification for the change, to include showing how the expected benefit from the planned use of the method will be realized in light of the change.

BASIC SET OF CORRECTIVE ACTIONS

Some consistent themes appear in the lists of corrective actions, regardless of problem area. These recommendations constitute the SEL's basic approach to regaining control of the project when danger signals arise:

- Stop current activities on the affected portion of the system and assess the problem
- Complete predecessor activities
- Decrease staff to manageable level
- Replace junior with senior personnel
- Increase and tighten management procedures
- Increase number of intermediate deliverables
- Decrease scope of work and define a manageable, doable thread of the system
- Audit project with independent personnel and act on their findings

SECTION 7—REVIEWS AND AUDITS

Reviews and audits are methods for assessing the condition of the project. Although both techniques address quality assurance by examining the plans, methods, and intermediate products associated with the development process, they are conducted for different reasons. Reviews are routinely scheduled as part of the development process; they mark key phase transitions in the software life cycle. Audits are generally not predetermined but are conducted when needed to evaluate the project's status.

REVIEWS

Reviews are designed to provide regularly scheduled monitoring of project status. The following four questions can serve as general guidelines, regardless of the type of review:

Is the development plan being followed?

Is the project making satisfactory progress?

Are there indications of future problems?

Is the team prepared to proceed with the next phase of development?

Reviews may be characterized in various ways, such as formality or timing. Informal reviews may be held to brief higher level managers on the current state of the project. In the SEL environment, an informal review is generally held following completion of each build. It covers important points that need to be assessed before the next phase of implementation is begun, such as changes to the design, schedules, and lessons learned.

A formal review generally involves a more detailed presentation and discussion and follows a prescribed agenda. Some reviews may resemble progress reports delivered at fixed intervals, e.g., weekly or monthly. In the SEL environment, five formal reviews are recommended — system requirements review **(SRR)**, software specifications review **(SSR)**, preliminary design review **(PDR)**, critical design review **(CDR)**, and operational readiness review **(ORR).** These reviews are scheduled at key transition points between life cycle phases (see Figure 7-1).

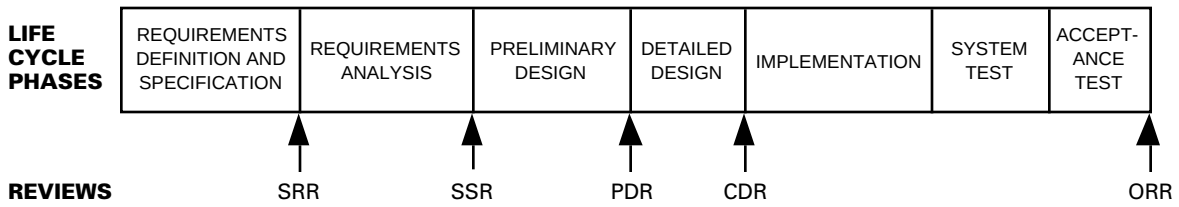


Figure 7-1. Scheduling of Formal Reviews

The remainder of this section examines the five reviews in order of occurrence and describes the **format of the review** (presenters, participants, and agenda), **key issues** to be addressed at the review (in addition to the general questions above), and **hardcopy material** (outline and suggested contents). The hardcopy material will contain some of the same information found in the documents described in Section 4. For example, when preparing the hardcopy material for the

PDR, some of the contents from the completed preliminary design report can be used. The manager should also keep in mind that, as with the documents in Section 4, there is some flexibility in selecting the most appropriate information to include in the hardcopy material. The contents suggested in this section are intended as a guideline.

SYSTEM REQUIREMENTS REVIEW

SRR Format

Presenters — requirements definition team

Participants

- Customer representatives
- User representatives
- CCB
- Senior development team representative(s)
- QA representatives

Time — after requirements definition is complete and before the requirements analysis phase begins

Agenda — selective presentation of system requirements, highlighting operations concepts and critical issues (e.g., TBD requirements)

Materials Distribution

- The requirements and functional specifications document is distributed 1 to 2 weeks prior to SRR
- Hardcopy material is distributed a minimum of 3 days before the SRR

Key Issues To Be Addressed

What is the effect of the TBD items?

What timetable has been established for resolving TBD items?

Have all external interface requirements been defined?

Are operational methods and performance constraints understood (e.g., timing, accuracy)?

Is the project feasible, given the constraints on and assumptions about available resources?

SRR Hardcopy Material

An outline and suggested contents of the SRR hardcopy material are presented in Figure 7-2.

1. **Agenda** — outline of review material
2. **Introduction** — purpose of system and background of the project
3. **Requirements summary** — review of top-level (basic) requirements developed to form the functional specifications
   a. Background of requirements — overview of project characteristics and major events
   b. Derivation of requirements — identification of input from project office, support organization, and system engineering organization used to formulate the requirements: support instrumentation requirements document (SIRD), memoranda of information (MOIs), and memoranda of understanding (MOUs)
   c. Relationship of requirements to level of support provided — typical support, critical support, and special or contingency support
   d. Organizations that provide system and support input and receive system output
   e. Data availability — frequency, volume, and format
   f. Facilities — target computing hardware and environment characteristics
   g. Requirements for computer storage, failure/recovery, operator interaction, system error recovery, and diagnostic output
   h. Requirements for support and test software — data simulators, test programs, and utilities
   i. Overview of the requirements and functional specifications document — its evolution, including draft dates and reviews and outline of contents
4. **Interface requirements** — summary of human, special-purpose hardware, and automated system interfaces, including references to interface agreement documents (IADs) and interface control documents (ICDs)
5. **Performance requirements** — system processing speed, system response time, system failure recovery time, and output data availability
6. **Environmental considerations** — special computing capabilities, e.g., graphics, operating system limitations, computer facility operating procedures and policies, support software limitations, database constraints, resource limitations, etc.
7. **Derived system requirements** — list of those requirements not explicitly called out in the requirements document but representing constraints, limitations, or implications that must be satisfied to achieve the explicitly stated requirements
8. **Operations concepts**
   a. High-level diagrams of operating scenarios showing intended system behavior from the user's viewpoint
   b. Sample input screens, menus, etc.; sample output displays, reports, plots, etc; critical control sequences
9. **Requirements management approach**
   a. Description of controlled documents, including scheduled updates
   b. Specifications/requirements change control procedures
   c. System enhancement/maintenance procedures
10. **Personnel organization and interfaces**
11. **Milestones and suggested development schedule**
12. **Issues, TBD items, and problems** — a characterization of all outstanding requirements issues and TBDs, an assessment of their risks (including the effect on progress), and a course of action to resolve them, including required effort, schedule, and cost

Figure 7-2. SRR Hardcopy Material

SOFTWARE SPECIFICATIONS REVIEW

SSR Format

Presenters — software development team

Participants

- Requirements definition team
- Customer representatives
- User representatives
- QA representatives for both teams
- CCB

Time — after requirements analysis is completed and before preliminary design is begun

Agenda — selective presentation of the results of requirements analysis, directed primarily toward project management and the end-users of the system

Materials Distribution

- The requirements analysis report and software development/management plan are distributed 1 to 2 weeks prior to SSR
- Hardcopy material is distributed a minimum of 3 days before the SSR

Key Issues To Be Addressed

Have all requirements and specifications been classified (as mandatory, derived, "wish list", information only, or TBD)?

Is the reuse proposal realistic in view of software availability and cost drivers?

Is the selected system architecture an appropriate framework for satisfying the requirements?

Are the requirements and functional specifications testable as written?

Have all requirements issues and technical risks been addressed?

Is the foundation adequate to begin preliminary design?

SSR Hardcopy Material

An outline and suggested contents of the SSR hardcopy material are presented in Figure 7-3.

1. **Agenda** — outline of review material
2. **Introduction** — background of the project and purpose of system
3. **Analysis overview** — analysis approach, degree of innovation required in analysis, special studies, and results
4. **Revisions since SRR** — changes to operations concepts, requirements, and functional specifications effected following the SRR
5. **Reusable software summary**
   a. Key reuse candidates — identification of existing software components that satisfy specific system functional specifications exactly or that will satisfy them after modification
   b. Overall architectural concept for the system
   c. Matrix of requirements to be fulfilled by reused components
6. **Classification summary**
   a. List of requirements and functional specifications with their assigned classifications (mandatory, derived, "wish list", information only, or TBD)
   b. Problematic specifications — identification and discussion of conflicting, ambiguous, i nfeasible, and untestable requirements and specifications
   c. Unresolved requirements/operations issues, including the dates by which resolutions to TBDs are needed
7. **Functional specifications**
   a. High-level data flow diagrams showing input, transforming processes, and output
   b. Data set definitions for interfaces to the system
8. **Development considerations**
   a. System constraints — hardware availability, operating system limitations, and support software limitations
   b. Utility, support, and test programs — list of auxiliary software required to support development, e.g., data simulators, special test programs, software tools, etc.
   c. Testing requirements
   d. Development assumptions
9. **Risks**, both to costs and schedules — includes risks related to TBD or changing requirements as well as technical risks
10. **Summary of planned prototyping efforts** needed to resolve technical risks, including the goals and schedule for each effort
11. **Personnel organization and interfaces**
12. **Milestones and schedules** — includes development life cycle (phase start and finish dates), schedule for reviews (internal and external), build/release dates, delivery dates of required external interfaces, schedule for integration of externally developed software and hardware

Figure 7-3. SSR Hardcopy Material

PRELIMINARY DESIGN REVIEW

PDR Format

Presenters — software development team

Participants

- Requirements definition team
- QA representatives from both groups
- Customer interfaces for both groups
- User representatives
- CCB

Time — after the functional design is complete and before the detailed design phase begins

Agenda — selective presentation of the preliminary design of the system. The materials presented at PDR do not necessarily show the technical depth that the development team has achieved during the preliminary design phase (e.g., presentation of operating scenarios should be limited to the nominal operating and significant contingency cases). Full details of the technical effort are documented in the preliminary design report

Materials Distribution

- The preliminary design report is distributed at least 1 week prior to PDR
- Hardcopy material is distributed a minimum of 3 days before PDR

Key Issues To Be Addressed

Have alternative design approaches been examined?

Are all requirements traceable to subsystems in the functional design?

Is the subsystem partitioning sensible in view of the required processing?

Are all interface descriptions complete at both the system and subsystem level?

Are operational scenarios completely specified?

Is the error handling and recovery strategy comprehensive?

Is the estimate of resources realistic?

Is the schedule reasonable?

Have technical risks, including any remaining TBD requirements, been adequately addressed?

Has the design been elaborated in baseline diagrams to a sufficient level of detail? (Reference 2 presents information on level of detail)

Does the design facilitate testing?

PDR Hardcopy Material

An outline and suggested contents of the PDR hardcopy material are presented in Figure 7-4.

1. **Agenda** — outline of review material
2. **Introduction** — background of the project and system objectives
3. **Design overview**
   a. Design drivers and their order of importance (e.g., performance, reliability, hardware, memory considerations, programming language, etc.)
   b. Results of reuse tradeoff analyses (at the level of subsystems and major components)
   c. Changes to the reuse proposal since the SSR
   d. Critique of design alternatives
   e. Diagram of selected system design. Shows products generated, interconnections among subsystems, external interfaces. Emphasis should be on the differences between the system to be developed and existing, similar systems
   f. Mapping of external interfaces to ICDs and ICD status
4. **System operation**
   a. Operations scenarios/scripts — one for each major product that is generated. Includes the form of the product and the frequency of generation. Panels and displays should be annotated to show what various selections will do and should be traced to a subsystem
   b. System performance considerations
5. **Major software components** — one diagram per subsystem
6. **Requirements traceability matrix** mapping requirements to subsystems
7. **Testing strategy**
   a. How test data are to be obtained
   b. Drivers/simulators to be built
   c. Special considerations for Ada testing
8. **Design team assessment** — technical risks and issues/problems internal to the software development effort; areas remaining to be prototyped
9. **Software development/management plan** — brief overview of how the development effort is conducted and managed
10. **Software size estimates** — one slide
11. **Milestones and schedules** — one slide
12. **Issues, problems, TBD items** beyond the control of the software development team
    a. Review of TBDs from SSR
    b. Dates by which TBDs/issues must be resolved

Figure 7-4. PDR Hardcopy Material

CRITICAL DESIGN REVIEW

CDR Format

Presenters — software development team

Participants

- Requirements definition team
- QA representatives from both groups
- Customer interfaces for both groups
- User representatives
- CCB

Attendees should be familiar with the project background, requirements, and design.

Time — after the detailed design is completed and before implementation is begun

Agenda — selective presentation of the detailed design of the system. Emphasis should be given to changes to the high-level design, system operations, development plan, etc. since PDR. Speakers should highlight these changes both on the slides and during their presentations, so that they become the focus of the review

Materials Distribution

- The detailed design document should be distributed at least 10 days prior to CDR
- CDR hardcopy material is distributed a minimum of 3 days in advance

Key Issues To Be Addressed

Are all baseline diagrams complete to the subroutine level?

Are all interfaces — external and internal — completely specified at the subroutine level?

Is there PDL or equivalent representation for each subroutine?

Will an implementation of this design provide all the required functions?

Does the build/release schedule provide for early testing of end-to-end system capabilities?

CDR Hardcopy Material

An outline and suggested contents of the CDR hardcopy material are presented in Figure 7-5.

1. **Introduction** — background of the project, purpose of the system, and an agenda outlining review materials to be presented
2. **Design overview** — major design changes since PDR (with justifications)
   a. Design diagrams, showing products generated, interconnections among subsystems, external interfaces
   b. Mapping of external interfaces to ICDs and ICD status
3. **Results of prototyping efforts**
4. **Changes to system operation** since PDR
   a. Updated operations scenarios/scripts
   b. System performance considerations
5. **Changes to major software components** since PDR (with justifications)
6. **Requirements traceability matrix** mapping requirements to major components
7. **Software reuse strategy**
   a. Changes to the reuse proposal since PDR
   b. New/revised reuse tradeoff analyses
   c. Key points of the detailed reuse strategy, including software developed for reuse in future projects
   d. Summary of RSL use — what is used, what is not, reasons, statistics
8. **Changes to testing strategy**
   a. How test data are to be obtained
   b. Drivers/simulators to be built
   c. Special considerations for Ada testing
9. **Required Resources** — hardware required, internal storage requirements, disk space, impact on current computer usage, impacts of compiler
10. **Changes to the software development/management plan** since PDR
11. **Implementation dependencies (Ada Projects)** — the order in which components should be implemented to optimize unit/package testing)
12. **Updated software size estimates**
13. **Milestones and schedules** including a well thought-out build plan
14. **Issues, risks, problems, TBD items**
    a. Review of TBDs from PDR
    b. Dates by which TBDs and other issues must be resolved

Figure 7-5. CDR Hardcopy Material

OPERATIONAL READINESS REVIEW

ORR Format

Presenters — operations support team and development team

Participants

- User acceptance test team
- Requirements definition, software development, and software maintenance representatives
- QA representatives from all groups
- Customer interfaces for all groups
- CCB

Time — after acceptance testing is complete and 90 days before operations start

Agenda — selective presentation of information from the hardcopy material, omitting details that are more effectively communicated in hardcopy form and highlighting critical issues (e.g., items 7 and 8 from Figure 7-6)

Materials Distribution

- ORR hardcopy material is distributed a minimum of 5 days before ORR

Key Issues To Be Addressed

What is the status of required system documentation?

What is the status of external interface agreements?

Were the methods used in acceptance testing adequate for verifying that all requirements have been met?

What is the status of the operations and support plan?

Is there sufficient access to necessary support hardware and software?

Are configuration control procedures established?

What contingency plans to provide operational support have been addressed?

ORR Hardcopy Material

An outline and suggested contents of the ORR hardcopy material are presented in Figure 7-6.

1. **Introduction** — purpose of the system and outline of review material

2. **System requirements summary** — review of top-level (basic) requirements
   a. Background of requirements — overview of project characteristics, major events, and support
   b. Derived requirements (updated from SRR)
   c. Relationship of requirements to support provided — typical, critical, and special or contingency support
   d. Operational support scenarios
   e. Relationship of requirements matrix, e.g., of top-level requirements to operational support scenarios
   f. Organizational interfaces, e.g., that provide system and support input and receive system output
   g. Data availability for the operating scenarios — frequency, volume, and format
   h. Facilities — computing hardware, environment characteristics, communications protocols, etc.
   i. General system considerations — high-level description of requirements for computer storage, graphics,and failure/recovery; operator interaction; system error recovery and diagnostic output; etc.
   j. Support and test software considerations — high-level description of requirements for data simulators, test programs, and support utilities

3. **Summary and status of IADs** — status of all interface documents with external organizations

4. **Support system overview**
   a. Major software components — purpose, general characteristics, and operating scenarios supported by programs and subsystems
   b. Testing philosophy
   c. Requirements verification philosophy — demonstration of methods used to ensure that the software satisfies all system requirements; matrix showing relation between requirements and tests
   d. Testing and performance evaluation results — summary of system integration and acceptance test results; evaluation of system performance measured against performance requirements
   e. System software and documentation status — summary of completed work packages and list of incomplete work packages with scheduled completion dates and explanation of delays

5. **Status of operations and support plan**
   a. Organizational interfaces — diagrams and tables indicating organizational interfaces, points of contact, and responsibilities; data flow and media (forms, tapes, voice, log)
   b. Data availability — nominal schedule of input and output data by type, format, frequency, volume, response tlme, turnaround time
   c. Facilities — nominal schedule of access to computers, support and special-purpose hardware, operating systems, and support software for normal, critical, emergency, and contingency operations
   d. Operating scenarios — top-level procedures, processing timelines, and estimated resources required
   e. Documentation of operations procedures — operations and support handbooks and update procedures

Figure 7-6. ORR Hardcopy Material (1 of 2)

6. **System management plan**
   a. Configuratlon control procedures — explanation of step-by-step procedures for maintaining system integrity, recovering from loss, fixing faults, and enhancing system
   b. Enhancement/maintenance procedures — initiation, forms, reviews, approval, and authorization
   c. Reporting/testing evaluation procedures — forms, reviews, approval, authorization, distribution
   d. System performance evaluation procedures — for ongoing evaluation
7. **Issues, TBD items, and problems**—a characterization of all those items affecting normal operations as perceived by the developers and users; an assessment of their effect on operations; and a course of action to resolve them, including required effort, schedule, and cost
8. **Contingency plans** — a priority list of items that could prevent normal operations, including the steps necessary to work around the problems, the defined levels of operations during the workarounds, and the procedures to attempt to regain normal operations
9. **Milestones and timeline of events** — diagrams, tables, and scripts of events; operating scenarios; maintenance; enhancement; reviews; training

Figure 7-6. ORR Hardcopy Material (2 of 2)

AUDITS

The purpose of an audit is to provide an independent assessment of the software project — its condition, its problems, and its likelihood of reaching successful completion. The audit may be prompted by indications of problems or by lack of progress, or it may be fulfilling a routine contractual requirement. Occurrence of one or more of the following conditions on a project should automatically trigger an audit:

- There are significant (> 25%) deviations from planned staffing, resources, or schedule after CDR
- There is a high turnover of staff (>30%)
- It is apparent that a delivery schedule will not be met
- The number of failed tests increases toward the end of system or acceptance testing
- It is determined that the system does not fulfill a critical capability
- There is evidence that system interfaces will not be met at delivery

An individual or, preferably, a group outside the development team is charged with conducting this examination. It is essential for the audit team to obtain a clear written statement of the specific objective of the audit at the start.

When preparing to conduct an audit, several key questions must be addressed:

What is the scope of the audit? Is the entire development effort being examined or only some particlar component of the project?

What is the final form the audit should take — a presentation, a written report, or both?

To whom will the results be presented?

What is the timetable for completing the audit?

What staff and support resources will be available for the audit work?

Have the development team and its management been informed that an audit is scheduled?

Have specific individuals on the development team been identified as principal contacts for the audit group?

What constraints exist on the work of the audit team regarding access to documents or individuals?

Where are the sources for documentation related to the project (requirements statements, plans, etc.)?

Are there specific auditing standards or guidelines that must be observed?

The answers to these questions will form the basis for planning the audit task. Sources of information include personal interviews with managers, team members, and individuals who interact with the development team. Documentation must be reviewed to understand the origin of the requirements and the plans and intermediate products of the development team.

Four steps are involved in conducting the audit of a software development project:

- Determine the current status of the project
- Determine whether the development process is under control
- Identify key items that are endangering successful completion
- Identify specific actions to put the project onto a successful course

AUDIT STEP #1 — DETERMINE THE CURRENT STATUS OF THE PROJECT

Audit Question	Audit Team's Checklist
Given the size and nature of the problem, where should the project be?	• Consult Table 3-1 and project histories data base (see Section 6) for comparison data on similar projects: — Percentage of effort and schedule consumed thus far — Percentage of effort by type of activity — Percentage of code developed thus far
According to the development/ management plan, where should the project be?	• Refer to the software development/ management plan for the project: — What activities should be current? — How should it be staffed? — What intermediate products should have been delivered? — What milestones should have occurred?
Where does the project actually stand now?	• From interviews and documentation, identify the following: current phase, milestones reached, documents delivered, activity levels, staff composition, project budget, and actual expenditures

AUDIT STEP #2 — DETERMINE WHETHER THE DEVELOPMENT PROCESS IS UNDER CONTROL

Audit Question	Audit Team's Checklist
Is the problem well understood and stable?	• Refer to review hardcopy materials (Figs. 7-2, 7-3, 7-4, 7-5) and the Requirements Analysis Report (Figure 4-4) for significance of TBD items • Determine the number of times project size has been reestimated and the extent of these revisions • From the technical manager, identify the number and extent of specification modifications received by the development team
Is the development/management plan being followed?	• Compare the development/management plan to actual development to determine whether — The schedule is being followed — Milestones have been met — The plan is being updated (see Section 2) — Actual and planned staffing levels agree
Is adequate direction being provided?	• Interview team leaders, technical managers, and administrative managers to determine whether there is agreement on — Project scope and objectives — Expectations and responsibilities at each level — Progress of the development effort to date

AUDIT STEP #3 — IDENTIFY KEY ITEMS THAT ARE ENDANGERING SUCCESSFUL COMPLETION

Audit Question	Audit Team's Checklist
Are resources adequate?	• Time — determine if lack of schedule time (regardless of staff) is a concern by comparison to past projects (Section 6) and by time estimates (Section 3)
	• Staff — compare actual with desired staffing characteristics as to level of effort (Section 3), staffing pattern (Figure 6-4), team size (Table 3-5), and composition (Table 3-6)
	• Computer — compare actual with expected utilization (Figures3-2 and 3-3); from interviews and computer facility schedules, determine degree of access to computer and level of service provided
	• Support — compare actual level of support services to typical levels
Is the development process adequate?	• Determine whether technical standards and guidelines are being followed for design, coding, and testing
	• Determine whether available tools and methodologies are being used
	• From interviews, determine the procedures for reporting and resolving problems
Are the organization and planning adequate?	• From interviews, assess the reporting relationships that exist, the team morale and turnover, and the pattern of delegating work
	• Assess the quality, completeness, and practicality of the software development/management plan (see Section 2)
	• From interviews and documentation (Sections 2 and 7), identify the extent of contingency planning

AUDIT STEP #4 — IDENTIFY SPECIFIC ACTIONS TO PUT THE PROJECT ON A SUCCESSFUL COURSE

- Recommended actions must be based on results of audit steps 1, 2, and 3
- For general problem of inadequate progress, some options are as follows
  - Stop development; generate a realistic plan before continuing
  - Replace junior personnel with senior staff
  - Increase visibility by improving identification and review of intermediate products
  - Provide training

APPENDIX A — SEL SOFTWARE DEVELOPMENT ENVIRONMENT

PROCESS CHARACTERISTICS	AVG.	HIGH	LOW
Duration (months)	24	43	19
Effort (staff-years)	14	32	3
Size (1000 source lines of code)	107	246	31
Staff (full time equivalent)			
Average	8	15	4
Peak	13	30	5
Individuals	22	44	6
Application Experience (years)			
Managers	9	15	4
Technical Staff	4	7	2
Overall Experience (years)			
Managers	14	19	10
Technical Staff	6	9	4

NOTES: **Type of software** Scientific, ground-based, interactive graphic
Machines IBM 4341 and DEC VAX 780, 8600, and 8810
Sample: 10 FORTRAN (with 15% in Assembler) and 3 Ada projects
Staff-year = 1864 effort hours

GLOSSARY

AGSS	attitude ground support system
ATR	Assistant Technical Representative
CCB	configuration control board
CDR	critical design review
CM	configuration management
COBE	Cosmic Background Explorer
CPU	central processing unit
ERBS	Earth Radiation Budget Satellite
GOADA	GOES Dynamics Simulator in Ada
GOES	Geostationary Operational Environmental Satellite
GRO	Gamma Ray Observatory
IAD	interface agreement document
ICD	interface control document
I/O	input/output
IV&V	independent verification and validation
LOC	lines of code
MOI	memorandum of information
MOU	memorandum of understanding
ORR	operational readiness review
PDL	program design language (pseudocode)
PDR	preliminary design review
QA	quality assurance
RSL	reusable software library
SEF	subjective evaluation form
SEL	Software Engineering Laboratory
SIRD	support instrumentation requirements document
SLOC	source lines of code
SME	Software Management Environment
SRR	system requirements review
SSR	software specifications review
TBD	to be determined
TCOPS	Trajectory Computation and Orbital Products System

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