5

DESIGN REVIEW AND EVALUATION

System design is an evolutionary process, progressing from an abstract notion to something that has form and function, is fixed, and can be reproduced in specified quantities to satisfy a designated consumer need. Initially, a requirement (or need) is identified. From this point, design evolves through a series of phases; that is, conceptual design, preliminary system design, and detail design and development, as illustrated in Figure 1.12.

As the design progresses, there are natural degrees of system definition. Requirements are defined, leading to a "functional" baseline. This includes the definition of operational requirements and the maintenance concept, trade-off study reports and the results of the feasibility analysis, the identification of technical performance measures (TPMs), and the system specification (Type "A"). Functional analysis and requirements allocation are accomplished, the results of which are defined through an "allocated" baseline. This baseline may be defined through a combination of development, process, product, and/or material specifications (Types "B," "C," "D," and "E") as applicable. This configuration is progressively expanded, through numerous iterations, until a "product" baseline is defined, and so on. These natural phases of system definition are reflected by the activities and milestones identified in Figure 1.26.

In viewing the overall design process, the necessary "checks and balances" must be incorporated to ensure that the system configuration being developed will indeed fulfill the initially specified requirements. These checks and balances, accomplished through the conductance of design reviews, are provided early in the system life cycle when changes can be accomplished with relative ease and usually without great cost. A design review and evaluation function must be integral within the design process. Within the design review function, there must be feedback provisions for corrective action and the incorporation of design changes as necessary. The basic philosophy of design evolution, with the necessary review and feedback provisions, is shown in

Figure 1.27. The purpose of this chapter is to explain this concept by describing evaluation methods, informal and formal design reviews, and the associated feedback and corrective-action loop.

5.1 DESIGN REVIEW AND EVALUATION REQUIREMENTS

One of the objectives in establishing a formal mechanism for design review and evaluation is to ensure, on a progressive and continuing basis, that the results of design reflect a configuration that will ultimately meet the stated consumer need.

Design evolves from the initial definition of requirements for a given system, through a series of iterations following a top-down approach, to a firm system configuration ready for production and/or construction. As one progresses through this series of steps, it is important that one initiate the requirements verification process from the beginning, because the earlier that potential problems are detected, the easier it will be to incorporate changes if needed. Thus, an ongoing design review and evaluation effort is required.

In evaluating the various stages of design, illustrated in Figures 1.12 and 3.1, the overall review process can be effectively accomplished through a combination of several approaches. First, there is an informal day-to-day review and evaluation activity that occurs as design decisions are made and data are developed (refer to Sections 2.9 and 2.10). This activity may involve many different design disciplines, making decisions on a relatively independent basis and generating design data based on the results. Second, formal design reviews are conducted at designated stages in the evolution of design, and these serve as a vehicle for communications and the formal approval of design data. These two main areas of activity are reflected in Figure 5.1 and are discussed further in Sections 5.2 and 5.3, respectively.

In response to the "WHYs" of design review, the objective is to ensure that system requirements are being met. These requirements, which are included in the system specification (refer to Section 3.2), are stated in both quantitative and qualitative terms. The purpose of the design review process is to evaluate the system configuration at different stages in terms of these requirements.

In addressing the aspect of "requirements," there are program-level requirements, system-level technical requirements, detailed design requirements at the component level, and so on. Not only these requirements are viewed in a hierarchical sense, but the level of emphasis placed on these requirements will shift as we progress from conceptual design to the detail design and development phase. For example, it may be appropriate to establish a hierarchical relationship of system parameters such as that shown in Figure 2.25. Many of these parameters can be expressed in terms of a specific quantitative measure of system performance; that is, the identification of a technical performance measure (refer to Section 2.6). Some of these measures are applicable at the system level, some are more appropriately applied at the subsystem level, and some are directly related to the assembly or component level. In any event, the system specification (and its supporting specifications) should establish the "order" of evaluation parameters on the basis of priority and importance.

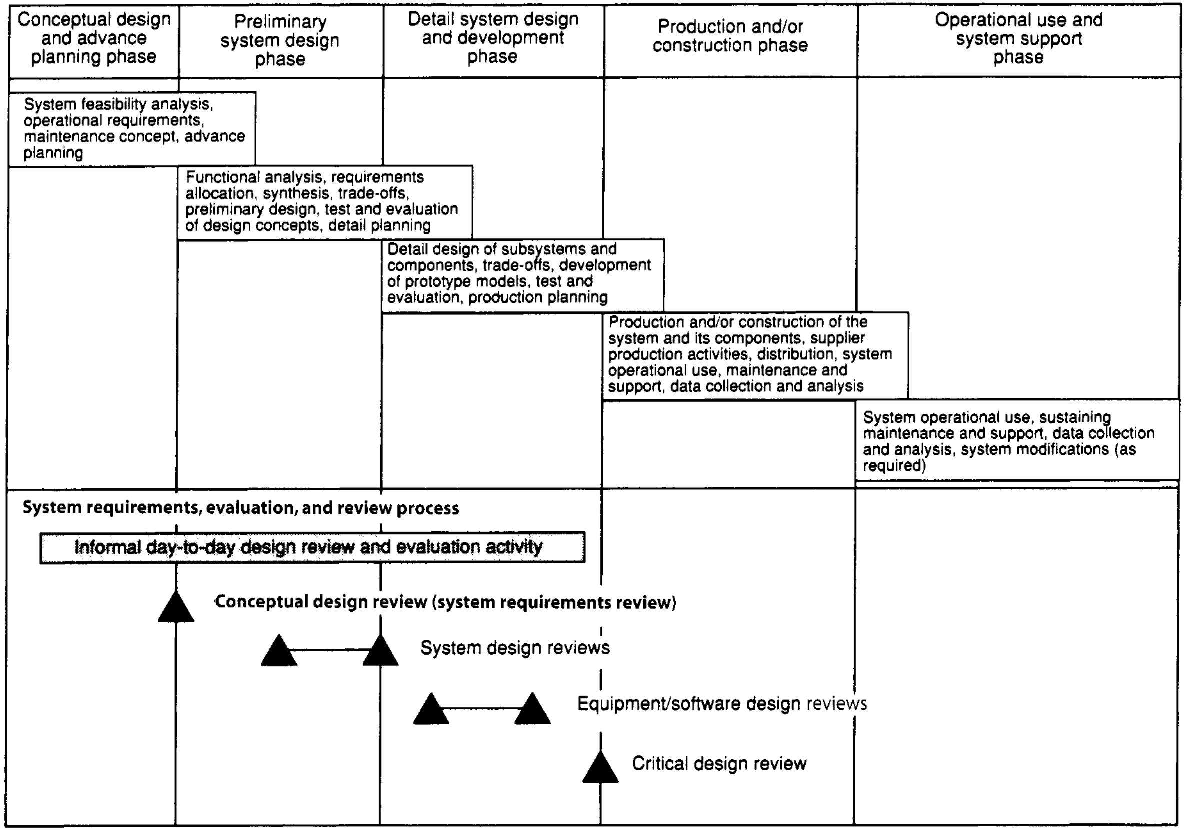


Figure 5.1 Design review and evaluation.

From the desired hierarchical relationship(s) of evaluation parameters, it is now possible to establish some specific criteria against which the results of design are compared. This, of course, leads to the identification of design review requirements for conceptual design, for preliminary system design, and for the detail design and development phase. In conceptual design, the design review process must address top system-level performance measures, functional-level relationships, and so on (as included in the System Type "A" Specification). In the detail design and development phase, although the system-level requirements are still important, the emphasis may be on the selection and standardization of parts, the mounting of components in a module design, the accessibility of an item requiring frequent maintenance, and the labeling of panel displays and controls. These factors must be integrated into the overall design review and evaluation process presented in Figure 5.1.

Given the criteria against which the design is to be evaluated, it is important to identify the disciplines that have the greatest impact on the design relative to compliance with a specific requirement. For instance, in meeting an equipment diagnostics requirement in the design of an electronics system, electrical engineering, mechanical engineering, and maintainability engineering, in accomplishing their respective design tasks, may have the greatest impact on the corrective maintenance downtime ($\overline{\mathrm{M}}\mathrm{ct}$) figure of merit for the system. In assessing the level of participation in the design review process, it is necessary that these design disciplines be adequately represented. In other words, along with identification of the criteria for evaluation, the design "responsibility" must be identified.

Design responsibility (and participation in design reviews) is covered further, from the organizational perspective, in subsequent sections of this text. However, at this point, it is worthwhile to consider some of the requirements for design review participation. As in Figure 2.25, a hierarchy of system evaluation parameters should be established and tailored for each major system being developed. Those parameters considered to be important can be identified, as shown in Figure 5.2. At the same time, a "degree-of-interest" relationship can be established between the various technical performance measures (TPMs) and the applicable disciplines participating in the design process. The level of interest indicated (i.e., high, medium, and low) pertains to the actual, or perceived, impact that the activity of the discipline has on a designated TPM for the system. This, in turn, should lead to establishing the organizational requirements for design review and evaluation as one progresses from conceptual design to the detail design and development phase. Sections 5.2 and 5.3 cover this area more comprehensively.

5.2 INFORMAL DAY-TO-DAY REVIEW AND EVALUATION

As shown in Figure 5.1, the design review and evaluation process includes two basic categories of activity: (1) an informal activity in which the results of design are reviewed and discussed on a day-by-day basis and (2) a structured series of formal design reviews conducted at specific times in the overall system development process.

Technical Performance Measures (TPMs) \ Engineering Design Functions	Aeronautical Engineering	Components Engineering	Cost Engineering	Electrical Engineering	Human Factors Engineering	Logistics Engineering	Maintainability Engineering	Manufacturing Engineering	Materials Engineering	Mechanical Engineering	Reliability Engineering	Structural Engineering	Systems Engineering
Availability (90%)	H	L	L	M	M	H	M	L	M	M	M	M	H
Diagnostics (95%)	L	M	L	H	L	M	H	M	M	H	M	L	M
Interchangeability (99%)	M	H	M	H	M	H	H	H	M	H	H	M	M
Life Cycle Cost ($350K / unit)	M	M	H	M	M	H	H	L	M	M	H	M	H
$\bar{M}ct$ (30 min.)	L	L	L	M	M	H	H	M	M	M	M	M	M
MDT (24 hrs.)	L	M	M	L	L	H	M	M	L	L	M	L	H
MMH/ OH (15)	L	L	M	L	M	M	H	L	L	L	M	L	H
MTBF (300 hrs.)	L	H	L	M	L	L	M	H	H	M	H	M	M
MTBM (250 hrs.)	L	L	L	L	L	M	H	L	L	L	M	L	H
Personnel Skill Levels	M	L	M	M	H	M	H	L	L	L	L	L	H
Size (150 ft. by 75 ft.)	H	H	M	M	M	M	M	H	H	H	M	H	M
Speed (450 mph.)	H	L	L	L	L	L	L	L	L	L	L	M	H
System Effectiveness (80%)	M	L	L	M	L	M	M	L	L	M	M	M	H
Weight (150K pounds)	H	H	M	M	M	M	M	H	H	H	L	H	M

H= high interest; M= medium interest; L= low interest

Figure 5.2 The relationship between TPMs and responsible design disciplines.

The output from the day-to-day informal activity leads into the formal design reviews; this relationship is shown in Figure 5.3.

Design is generally initiated by the electrical engineer, the mechanical engineer, the structural engineer, the process engineer, and/or others who are directly responsible for the design of various components of the system. The results, usually produced independently from these different sources, are described through a combina-

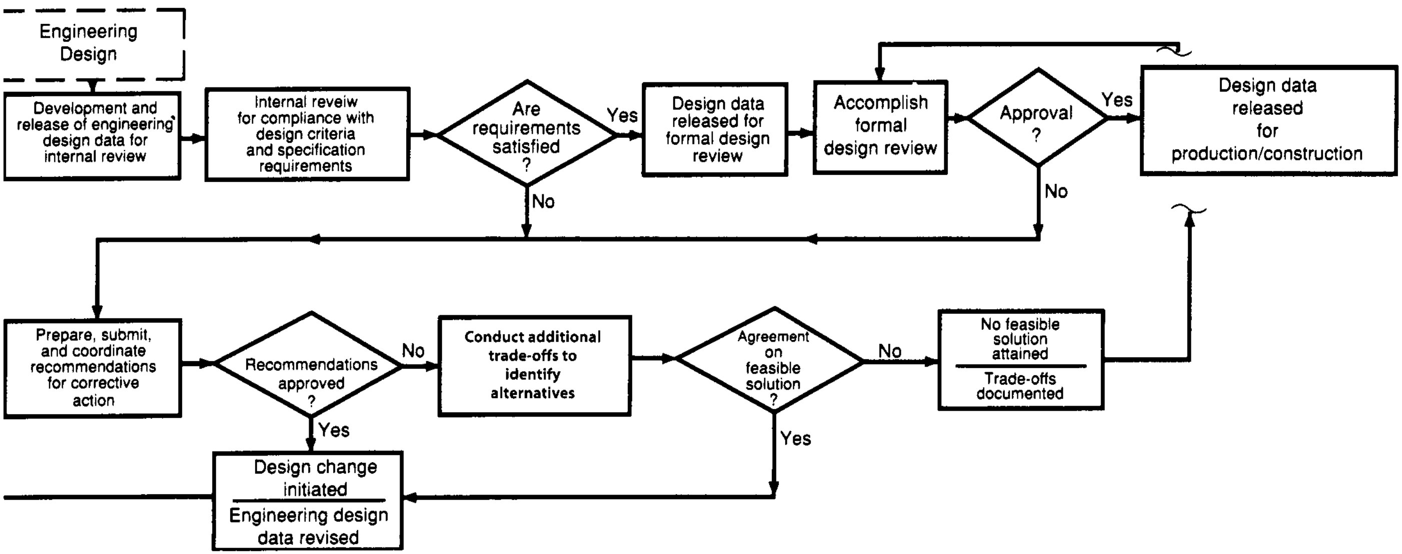


Figure 5.3 Design review and evaluation procedure.

tion of drawings, parts lists, reports, computerized databases, and supporting design documentation. As this definition process evolves, there are several major objectives:

1. The results of design must be properly communicated in a clear, effective, and timely manner to all members of the design team. Everyone involved in the design process must work from the *same* database.

2. The results of design must be compatible with the initially defined requirements for the system. Although each responsible designer should be familiar with the total spectrum of system requirements (e.g., electrical and reliability requirements), the physical separation of design disciplines and the lack of appreciation for the interfaces often result in discrepancies of one type or another (i.e., conflicts, omissions, incompatibilities between system components). These discrepancies must, of course, be corrected as soon as possible.

The design review activity is intended to satisfy both objectives. This can be accomplished through a series of steps involving the distribution of drawings, parts lists, and data to all affected areas of design, the review and sign-off of data for approval, the generation of recommendations for change in the event of noncompliance with a given requirement or for the purposes of product improvement, review of the change recommendations by the responsible designer, and so on. This is a day-to-day process with design data evolving from many different sources, and the amount of data can be rather extensive, depending on the nature of the system being developed and the size of the project.

In the past, particularly in regard to large projects in which members of the design team are remotely located from one another, the process of data distribution and approval has often been somewhat lengthy in terms of the time required to proceed through the cycle of events. For this reason, combined with the need for the designer to "get on with the design," many organizations have chosen to skip these steps of data distribution, review, and approval in the interest of saving time. In other words, the individual designer makes a decision (often independently), design documentation is prepared and released, component parts are procured and/or fabricated, and so on. Although it is hoped that all design interfaces have been recognized and that system requirements have been met, this has not always been the case. In the rush to complete the design, there have been omissions, conflicts, and/or problems associated with the incompatibility of system components. These problems have become evident later on during a formal design review (when formal design reviews have been conducted) or during system test and evaluation. Further, the implementation of design changes has been more costly than it might have been had these changes been incorporated earlier in the design process.[1]

Relative to the future, the implementation of the informal design review and evaluation process shown in Figure 5.3 is, of course, highly desirable. Yet this procedure has to be accomplished both efficiently and in a timely manner. Although the series of

[1]These problems can be partially solved through the implementation of an integrated database, as illustrated in Figure 2.31.

data review steps accomplished in the past may have been somewhat time-consuming, the advent of the computerized methods described in Chapter 4 should result in a definite improvement. The utilization of computer-aided design (CAD) technology and the establishment of a communications network, as illustrated in Figure 4.2, will help to ensure an efficient flow of the necessary information. Design data can be distributed to many different locations expeditiously and on a concurrent basis, data review and approval sign-off can be accomplished through the electronics media, and data revisions can be implemented in a relatively short time frame. With these capabilities available, it is hoped that the process illustrated in Figure 5.3 can be implemented in an effective manner.

Concerning the review and evaluation itself, the depth of the review is a function of the complexity of design, whether the item being designed is new (i.e., promoting the state of the art) or is made up of existing off-the-shelf components, and whether the item is being developed by an outside supplier or designed in-house. Items that are complex or include the application of new technology will be investigated to a greater extent than standard components that are available and have been used in other systems.

In evaluating a given design configuration for compliance with a specified set of requirements, the reviewer may wish to develop a series of checklists based on applicable criteria. For example, through the review of selected design standards, component parts data, human-factors anthropometric data, maintainability accessibility factors, safety standards, and so on, the various design review activities can develop criteria that are directly applicable to the system in question. These criteria, summarized in the form of a checklist, are referenced as the evaluation of a given item is being conducted. The checklist serves as an aid in facilitating the review process. Figure 5.4 shows a sample checklist identifying typical topic areas for system-level reviews. Figure 5.5 presents an example of some specific questions that amplify the topics in Figure 5.4. In preparing for the various informal day-to-day design reviews, checklists of this nature can be very helpful.[2]

The results from the day-to-day informal review process, in the context of approved (signed-off) design documentation, are identified as items to be addressed in the formal design review. This includes not only design drawings and parts lists, but also trade-off study reports that support critical design decisions.

5.3 FORMAL DESIGN REVIEWS

A *formal design review* constitutes a coordinated activity (i.e., a structured meeting or a series of meetings) directed toward the final review and approval of a given design configuration, whether it be the overall system configuration, a subsystem, or an element of the system. Although the informal day-to-day review process discussed in

[2]A sample design review checklist is included in Appendix D. The development of such a checklist, tailored to a particular system, can be very beneficial. The results of a QFD analysis indicating areas of importance in design can lead to the preparation of design-related questions which, when applied, can help to emphasize the nature of the criteria that should be reflected in the ultimate design configuration being reviewed. By asking the right questions, one can provide the proper emphasis where required.

System Design Review Checklist
General Requirements: Have the technical and program requirements for the system been adequately defined through 1. Feasibility Analysis 2. Operational Requirements 3. Maintenance Concept 4. Effectiveness Factors 5. Functional Analysis and Allocation 6. System Specification 7. Supplier Requirements 8. System Engineering Management Plan (SEMP)
Design Features: Does the design reflect adequate consideration of 1. Accessibility 2. Adjustments and Alignments 3. Cables and Connectors 4. Calibration 5. Data Requirements 6. Disposability 7. Ecological Requirements 8. Economic Feasibility 9. Environmental Requirements 10. Facility Requirements 11. Fasteners 12. Handling 13. Human Factors 14. Interchangeability 15. Maintainability 16. Mobility 17. Operability 18. Packaging and Mounting 19. Panel Displays and Controls 20. Personnel and Training 21. Producibility 22. Reconfigurability 23. Reliability 24. Safety 25. Selection of Parts/Materials 26. Servicing and Lubrication 27. Societal Requirements 28. Software 29. Standardization 30. Storage 31. Supportability 32. Support Equipment Requirements 33. Survivability 34. Testability 35. Transportability 36. Quality
In reviewing the design (layouts, drawings, parts lists, reports), this checklist may be beneficial in covering major program requirements and design features applicable to the system. The items listed are supported with more detailed questions and criteria included in Appendix D. The response to each item listed should be YES.

Figure 5.4 Sample design review checklist.

Section 5.2 covers specific aspects of the design, this coverage usually involves a series of independent fragmented efforts representing a variety of engineering disciplines. The purpose of the formal review is to provide a mechanism whereby *all* interested and responsible members of the design team can meet in a coordinated manner, communicate with each other, and agree on a recommended approach. The formal design review process usually includes the following steps:

1. A newly designed item, designated as being complete by the responsible design engineer, is selected for formal review and evaluation. The item may be the overall system configuration as an entity or a major element of the system, depending on the program phase and the category of review conducted.
2. A location, date, and time for the formal design review meeting are specified.

Detailed Design Review Checklist

18. Packaging and Mounting

    a. Is the packaging design attractive from the standpoint of consumer appeal (e.g., color, shape, size)?
    b. Is functional packaging incorporated to the maximum extent possible? Interaction effects between packages should be minimized, and it should be possible to limit maintenance to the removal of one module (the one containing the failed part) when a failure occurs and not require the removal of two, three, or four modules in order to solve the problem.
    c. Are equipment modules and/or components that perform similar operations electrically, functionally, and physically interchangeable?
    d. Is the packaging design compatible with the level-of-repair analysis decisions? Repairable items are designed to include maintenance provisions such as test points, accessibility, and plug-in components. Items classified as "discard-at-failure" should be encapsulated and maintenance provisions are not required.
    e. Are disposable modules incorporated to the maximum extent practical? It is highly desirable to reduce overall product support through a "no-maintenance" design concept as long as the items involved are high in reliability and relatively low in cost.
    f. Are plug-in modules and components utilized to the maximum extent possible (unless the use of plug-in components significantly degrades the equipment reliability)?
    g. Are the accesses between modules adequate to allow for hand grasping (refer to Design Handbook "X" for recommended accessibility provisions)?
    h. Are modules and components mounted such that the removal of any single item for maintenance will not require the removal of other items? Component stacking should be avoided where possible.
    i. In areas where component stacking is necessary because of limited space, are the modules mounted in such a way that access priority has been assigned in accordance with the predicted removal and replacement frequency? Items that require frequent maintenance should be more accessible.
    j. Are modules and components, not of the plug-in variety, mounted with four fasteners or less? Modules should be securely mounted, but the number of fasteners should be held to a minimum.
    k. Are shock-mounting provisions incorporated where shock and vibration requirements are excessive?
    l. Are provisions incorporated to preclude the installation of the wrong module?
    m. Are plug-in modules and components removable without the use of tools? If tools are required, they should be of the standard variety.
    n. Are guides (slides or pins) provided to facilitate module installation?
    o. Are modules and components properly labeled?

Figure 5.5 Partial listing of design review questions.

3. An agenda for the review is prepared, defining the scope and anticipated objectives of the review.

4. A design review board (DRB) representing the organizational elements and the disciplines *affected* by the review is established. Representation from electrical engineering, mechanical engineering, structural engineering, reliability engineering, logistics engineering, manufacturing or production, component suppliers, management, and other appropriate organizations is included as applicable. This representation, of course, will vary from one review to the next. A well-qualified and unbiased chairperson is selected to conduct the review.

5. The applicable specifications, drawings, parts lists, predictions and analysis results, trade-off study reports, and other data supporting the item being evaluated must be identified prior to the formal design review meeting and made available during the meeting for reference purposes as required. It is hoped that each of the selected design review board members will be familiar with the data prior to the meeting.

6. Selected items of equipment (breadboards, service test models, prototypes), mock-ups, and/or software may be utilized to facilitate the review process. These items, of course, must be identified early.

7. Reporting requirements and the procedures for accomplishing the necessary follow-up action(s) stemming from design review recommendations must be defined. Responsibilities and action-item time limitations must be established.

8. Funding sources for the necessary preparations, for conducting the formal design review meetings, and for the subsequent processing of outstanding recommendations must be identified.

The formal design review meeting generally includes a presentation (or a series of presentations) on the item being evaluated, by the responsible design engineer, to the selected design review board members. This presentation should cover the proposed design configuration, along with the results of trade-off studies and analyses that support the design approach. The objective is to summarize what has been established earlier through the informal day-to-day design activity. If the design review board members are adequately prepared, this process can be accomplished in an efficient manner.

The formal design review must be well organized and firmly controlled by the design review board chairperson. Design review meetings should be brief and to the point, objective in terms of allowing for *positive* contributions, and must not be allowed to drift away from the topics on the agenda. Attendance should be limited to those who have a direct interest in and can contribute to the subject matter being presented. Design specialists who participate should be authorized to speak and make decisions concerning their areas of specialty. Finally, the design review activity must make provisions for the identification, recording, scheduling, and monitoring of corrective actions. Specific responsibility for follow-up action must be designated by the design review board chairperson.

With the conductance of formal design review meetings, a number of purposes are served:

1. The formal design review meeting provides a forum for communications across the board. The necessary coordination and integration are not adequately accomplished through the informal day-to-day review process, even with the availability of computerized technology. "Person-to-person" contact is required.

2. It provides for the definition of a common configuration baseline for all project personnel; that is, everyone involved in the design process must work from the *same* baseline. The responsible design engineer is given an opportunity to explain the proposed design configuration, and representatives from the various supporting disciplines are provided an opportunity to learn of the designer's problems. This, in turn, creates a better understanding between design and support personnel.

3. It provides a means for solving outstanding interface problems, and it promotes the assurance that all elements of the system are compatible. Those conflicts that were not resolved through the informal day-to-day review are addressed. Moreover, those disciplines not properly represented through earlier activity are provided an opportunity to be heard.

4. It provides a formalized check (i.e., audit) of the proposed system/product design configuration with respect to specification and contractual requirements. Areas of noncompliance are noted, and corrective action is initiated as appropriate.

5. It provides a formal report of major design decisions that have been made and the reasons for making them. Design documentation, analyses, predictions, and trade-off study reports that support these decisions are properly recorded.

The conductance of formal design review meetings tends to increase the probability of mature design, as well as the incorporation of the latest design techniques where appropriate. Group reviews may lead to the identification of new ideas, the application of simplier processes, and the realization of cost savings. A good "productive" formal design review activity can be very beneficial. Not only can it cause a reduction in the producer's risk relative to meeting specification and contractual requirements, but the results often lead to an improvement in the producer's methods of operation.

As stated earlier, formal design review meetings are generally scheduled prior to each major evolutionary step in the design process; for example, after the definition of a functional baseline, but prior to the establishment of an allocated baseline. Although the quantity and type of design reviews scheduled may vary from program to program, four basic types are easily identifiable and common to most programs. They are the conceptual design review, the system design review, the equipment or software design review, and the critical design review. The relative time phasing of these reviews is illustrated in Figure 5.1.

5.3.1 Conceptual Design Review

The *conceptual design review* (or system requirements review) is usually scheduled toward the end of the conceptual design and prior to entering the preliminary system design phase of the program (preferably not longer than one to two months after program start). The objective is to review and evaluate the functional baseline for the system, and the material to be covered through this review should include the following:[3]

1. Feasibility analysis (the results of technology assessments and early trade-off studies justifying the system design approach being proposed)
2. System operational requirements

[3]It is recognized that some of these requirements may not be adequately defined during the conceptual design phase, and that the review of such may have to be accomplished later. However, in promoting the desired generic approach described herein (and particularly with regard to system engineering), maximum effort should be made to complete these requirements early, even though changes may be necessary as system design progresses. The object is to encourage (or "force") early system definition, even if the "baseline" changes later.

3. System maintenance concept
4. Functional analysis (top-level block diagrams)
5. Significant design criteria for the system (e.g., reliability factors, maintainability factors, and logistics factors)
6. Applicable effectiveness figures of merit (FOMs) and technical performance measures (TPMs)
7. System Specification (Type "A"; refer to Section 3.2 and Figure 3.2)
8. System Engineering Management Plan (SEMP)
9. Test and Evaluation Master Plan (TEMP)
10. System design documentation (layout drawings, sketches, parts lists, selected supplier components data)

The conceptual design review deals primarily with top *system-level requirements,* and the results constitute the basis for follow-on preliminary system design and development activity. Participation in this formal review should include selected representation from both the consumer and producer organizations. Consumer representation should involve not only those personnel who are responsible for the acquisition of the system (i.e., contracting and procurement), but also those who will ultimately be responsible for the operation and support of the system in the field. Individuals with experience in operations and maintenance should participate in the system requirements review. On the producer side of the spectrum, those lead engineers responsible for *system* design should participate, along with representation from various design disciplines and production (as necessary). It is important to ensure that the disciplines identified in Chapter 3 are adequately represented in the formal design review process from the beginning.

In summary, the conceptual design review is extremely important for all concerned, as it represents the first opportunity for formal communication relative to system requirements from the top down. It can provide an excellent baseline for all subsequent design effort. Unfortunately, for many projects in the past, the conductance of a conceptual design review has not been accomplished. Further, if such a review were conducted, the results were not always made available to responsible design engineering personnel assigned to the project. This, in turn, has resulted in a series of efforts conducted in somewhat of a vacuum and not well coordinated or integrated. Thus, with the objectives of system engineering in mind, it is essential that a good functional baseline for the system be defined and properly evaluated through the conductance of an effective conceptual design review.

5.3.2 System Design Reviews

System design reviews are generally scheduled during the preliminary design phase when functional requirements and allocations are defined, preliminary design layouts and detailed specifications are prepared, system-level trade-off studies are conducted, and so on (refer to Figure 5.1). These reviews are oriented to the overall system configuration, rather than individual equipment items, software, and other components of the system. As the design evolves, it is important to ensure that the requirements described in the system specification are maintained. There may be one or more formal reviews scheduled, depending on the size of the system and the complexity of design. System design reviews cover a variety of topics, such as the following:

1. Functional analysis and the allocation of requirements (beyond what is covered in the conceptual design review).
2. Development, process, product, and material specifications as applicable (Types "B," "C," "D," and "E").
3. Design data defining the overall system (layouts, drawings, parts/materials lists, supplier data).
4. Analyses, reports, predictions, trade-off studies, and related design documentation. This includes material that has been prepared in support of the proposed design configuration, and analyses/predictions that provide an assessment of what is being proposed. Reliability and maintainability predictions, logistic support analysis data, and so on, are included.
5. Assessment of the proposed system design configuration in terms of applicable technical performance measures (TPMs).
6. Individual program/design plans (e.g., reliability and maintainability program plans, human-factors program plan, and logistics plan).

Participation in system design reviews should include representation from both the consumer and producer organizations, as well as from major suppliers involved in the early phases of the system life cycle.

5.3.3 Equipment/Software Design Reviews

Formal design reviews covering equipment, software, and other components of the system are scheduled during the detail design and development phase of the life cycle. These reviews, usually oriented to a particular item, include coverage of the following:

1. Process, product, and material specifications (Types "C," "D," and "E"—beyond what is covered in the system design reviews).
2. Design data defining major subsystems, equipment, software, and other elements of the system as applicable (assembly drawings, specification control drawings, construction drawings, installation drawings, logic diagrams, schematic diagrams, materials and detailed parts lists, and so on).
3. Analyses, reports, predictions, trade-off studies, and other related design documentation as required in support of the proposed design configuration and/or for assessment purposes. Reliability and maintainability predictions, human-factors task analysis, supportability analysis data, and so on, are included.
4. Assessment of the proposed system design configuration in terms of the applicable technical performance measures (TPMs). An ongoing review and evalu-

ation are required to ensure that these system-level requirements are maintained throughout the various stages of detail design and development.

5. Engineering breadboards, laboratory models, service test models, mock-ups, and prototype models used to support the specific design configuration being evaluated.
6. Supplier data covering specific components of the system as applicable (drawings, materials and parts lists, analysis and prediction reports, and so on).

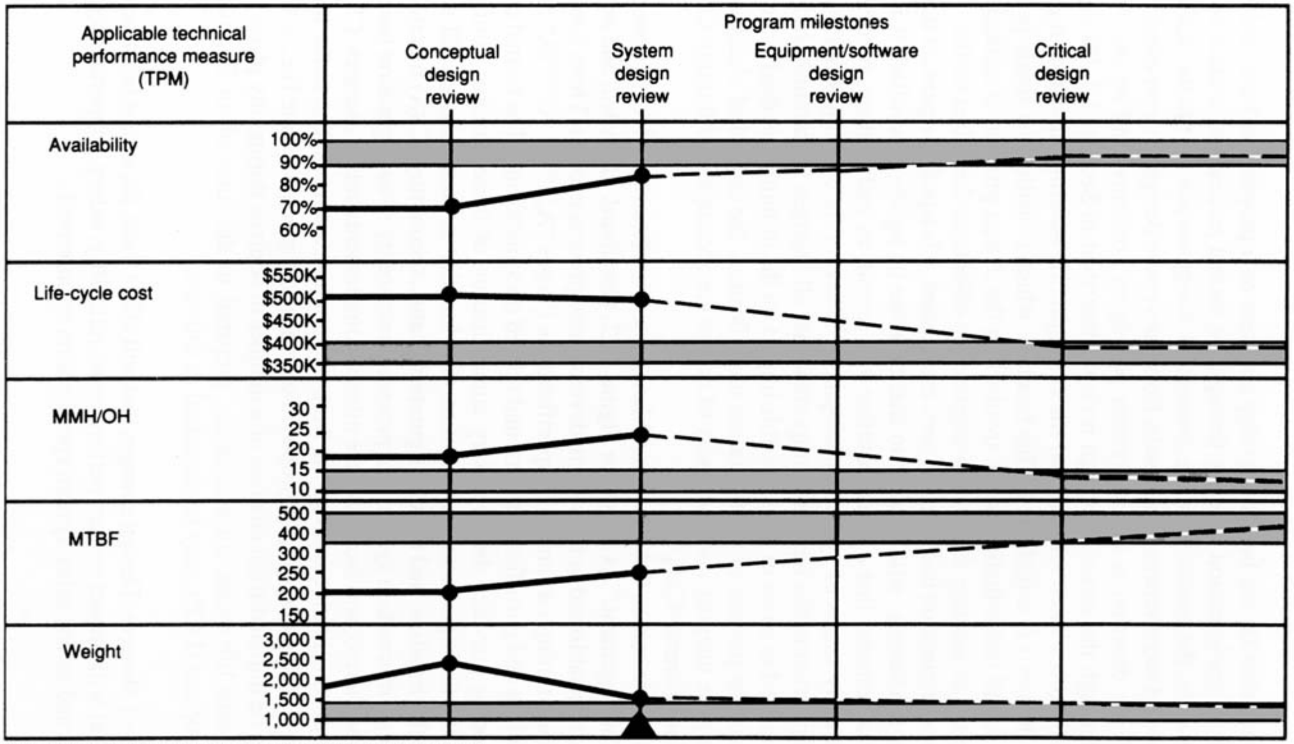
Participation in these formal reviews should include representation from the consumer (i.e., customer), producer (i.e., contractor), and applicable supplier organizations.

5.3.4 Critical Design Review

The *critical design review* is generally scheduled after the completion of detail design, but prior to the release of firm design data for production or construction. Design is essentially "frozen" at this point, and the proposed configuration is evaluated in terms of adequacy and producibility. The critical design review may address the following:

1. A complete set of final design documentation covering the system and its components (manufacturing drawings, materials and parts lists, supplier component parts data, drawing change notices, and so on).
2. Analyses, predictions, trade-off studies, test and evaluation results, and related design documentation (final reliability and maintainability predictions, human-factors and safety analyses, logistic support analysis records, test reports, and so on).
3. Assessment of the final system design configuration (i.e., the product baseline) in terms of applicable technical performance measures (TPMs).
4. A detailed production/construction plan (description of proposed manufacturing methods, fabrication processes, quality control provisions, supplier requirements, material flow and distribution requirements, schedules, and so on).
5. A final logistics and maintenance support plan covering the proposed life-cycle maintenance and support of the system throughout the consumer utilization phase.

The results of the critical design review describe the final system/product configuration baseline prior to entering into production and/or construction. This review constitutes the last in a series of progressive evaluation efforts, reflecting design and development from a historical perspective and showing growth and maturity in design as the engineering project evolved. It is important to view the design review process in *total* and to provide an overall evaluation of certain designated system attributes as the project progresses, particularly because close continuity is required between the various reviews. An example of designated system attributes that should be assessed on a continuing basis is presented in Figure 5.6.



Note: The shaded area represents the desired goal.

Figure 5.6 System parameter measurement and evaluation at design review (sample).

5.4 THE DESIGN CHANGE AND SYSTEM MODIFICATION PROCESS

The objective thus far has been to develop a system on a progressive basis and to establish a firm configuration baseline through the formal review and evaluation process. In essence, the results from the conceptual design review lead to the definition of system-level requirements, the results from the system design reviews constitute a more in-depth description of the system packaging concepts, and so on. As we progress through the series of design reviews described in Section 5.3, the system definition becomes more refined, and the configuration baseline (updated from one review to the next) is established. This baseline, which constitutes a single point of reference for all individuals who are involved in the design process, is critical from the standpoint of meeting the system engineering objectives described earlier.

Once a configuration baseline has been established, it is equally important that any variations, or changes, with respect to that baseline be tightly controlled. It is certainly not anticipated that a given baseline will remain as such forever, particularly during the early stages of system development. However, in evolving from one design configuration to the next, it is important that all changes be carefully recorded and documented in terms of their possible impact on the initially specified system requirements. The process of configuration identification, the control of changes, and maintaining the integrity and continuity of design are accomplished through Configuration Management (CM).[4]

In the defense sector, Configuration Management is often related to the concept of "baseline management." As shown in Figure 1.12, *functional, allocated,* and *product* baselines are established as the system development process evolves. These baselines are described through a family of specifications (Types "A," "B," "C," "D," and/or "E"), drawings and parts lists, reports, and related documentation. The formal design review process provides the necessary authentication of these baseline configurations, and the Configuration Identification (CI) function is accomplished. CI relates to a particular baseline, and the Configuration Status Accounting (CSA) function is a management information system that provides traceability of configuration baselines and changes thereto, and facilitates the effective implementation of changes. CSA includes the documentation in evolving from one configuration baseline to the next.

Proposed design changes, or proposed changes to a given baseline (i.e., a CI design), may be initiated from any one of a number of sources during any phase in the overall system life cycle. Such changes, prepared in the form of an Engineering Change Proposal (ECP), may be classified as follows:

1. *Class I changes:* Design changes that will affect form, fit, and/or function (e.g., changes that will impact system performance, reliability, safety, supportability, life-cycle cost, and/or any other system specification requirement).

[4]Configuration Management (CM) is the process that identifies the functional and physical characteristics of an item during its life cycle, controls changes to those characteristics, and records and reports change processing and implementation status.

2. *Class 2 changes:* Design changes that are relatively minor in nature and that will not affect system specification requirements (e.g., changes covering material substitutions, documentation clarifications, drawing nomenclature, producer deficiencies).

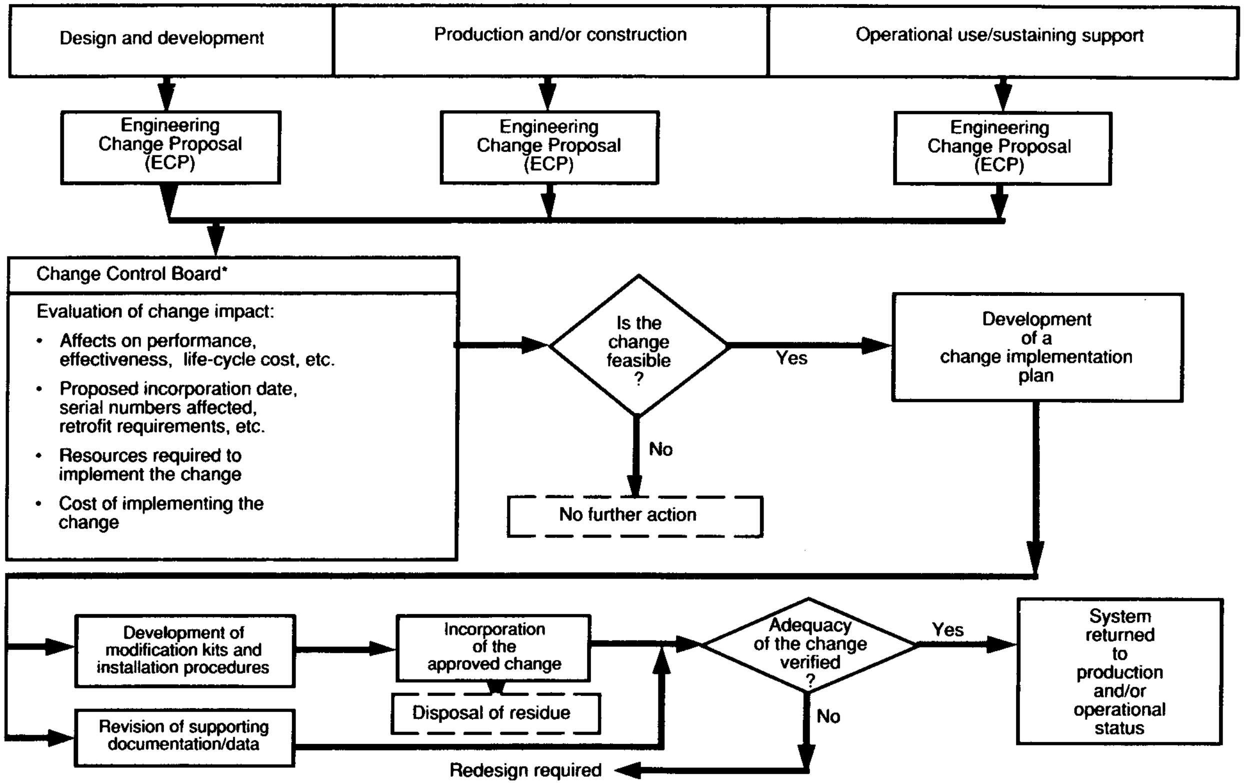
Changes may be categorized as "emergency," "urgent," or "routine," depending on priority and on the criticality of the change.

A simplified version of the system control procedure is illustrated in Figure 5.7. Proposed changes to a given baseline may be initiated during any phase of system development, production, and/or operational use. Each proposed change is presented in the form of an Engineering Change Proposal (ECP) submitted for review, evaluation, and approval. In general, each ECP should include the following:[5]

1. A statement of the problem and a description of the proposed change.
2. A brief description of alternatives that have been considered in responding to the need.
3. An analysis showing how the change will solve the problem.
4. An analysis showing how the change will impact system performance, effectiveness factors, packaging concepts, safety, elements of logistic support, life-cycle cost, and so on. What are the impacts (if any) on system specification requirements? What is the effect on life-cycle cost?
5. An analysis to ensure that the proposed solution will not cause the introduction of new problems.
6. A preliminary plan for incorporating the change; that is, proposed date of incorporation, serial numbers affected, retrofit requirements, and verification test approach (as applicable).
7. A description of the resources required to implement the change.
8. An estimate of the costs associated with implementing the change.
9. A statement covering the impact on the system if the proposed change is *not* implemented; that is, an identification of the possible risks associated with a "do-nothing" decision.

As shown in Figure 5.7, engineering change proposals (ECPs) are processed through the Change Control Board (sometimes known as the "Configuration Control Board," or the CCB) for review and evaluation. The CCB should function in a manner similar to the Design Review Board (DRB) discussed in Section 5.3. Board representation should cover those design disciplines impacted by the change, in-

[5]In many organizations, the procedures related to configuration management and change control are a little more complex than those presented here. The procedure may involve engineering change requests (ECRs), design revision notices (DRNs), interface control documents (ICDs), and so on. The objective here is to present a *simplified* approach, providing a basic understanding of the importance of change control as part of the system engineering process



*This activity also known as the "Configuration Control Board (CCB)".

Figure 5.7 System change control procedure.

cluding customer and supplier representation as necessary. Not only is it necessary to review and evaluate the original design, but it is important to ensure that all proposed design changes are handled in a similar manner. On occasion, when project schedules are "tight," the designer will generate data just to have something available for the record, and the *real* design configuration will be reflected through the "change process." Although this is not a preferred practice, it does occur in a number of instances when the objective is to save time. In any event, the review of design changes must be treated with the same degree of importance as is specified for the formal design review.

On completion of the formal design change review by the CCB, approved ECPs will be supported with the development of a plan for incorporating the change(s) in the system. This plan should include coverage of not only the modifications required for the prime equipment, but also the modifications associated with test and support equipment, spares and repair parts, facilities, software, and technical documentation. All elements of the system must be addressed on an integrated basis.

The actual incorporation of changes to the system is accomplished using a variety of approaches, depending on when the change is to be implemented. The time of implementation is a function of priority and/or criticality. Emergency or urgent changes may require immediate action, whereas routine changes may be grouped and incorporated at some convenient later point in time. Approved changes initiated during system design and development, prior to the availability of any hardware, software, or other physical components, may be incorporated through the preparation of design change notices (DCNs), or equivalent, attached to the applicable drawings/documentation covering those areas of design affected by the change. As the project progresses, these "paper" (or database) changes will be reflected in the new design configuration.

In the event that changes are initiated during the production/construction phase when multiple quantities of identical items are being produced, a designated serial-numbered item needs to be identified to indicate effectivity; that is, the change will be incorporated on the production line in Serial Number "X" and on later models. This should ensure that all applicable items scheduled to be produced in the future will automatically reflect the updated configuration.

For those system components that are already in use, changes may be incorporated through the installation of a modification kit in the field at the consumer's operational site. Such kits are installed, and the system is tested to verify the adequacy of the change. At the same time, the system support capability (e.g., test equipment, spares, and technical data) needs to be upgraded for compatibility with the prime mission-oriented segments of the system. Optimally, the installation process should take place at a time when the system is not in demand or being utilized in the performance of a mission.

This overall process is illustrated in Figure 5.7. With the incorporation of validated changes, the system configuration is updated and a new baseline is established. In situations in which the adequacy of the change is not verified, some additional redesign may be required.

5.5 SUMMARY

This chapter primarily addresses the basic review, evaluation, and feedback process illustrated in Figure 1.27. This process, which is critical in regard to the objectives of system engineering, must be tailored to the specific system development effort and must be properly controlled. An ongoing measurement and evaluation activity is essential and must be initiated from the beginning. Performing a one-time review and evaluation after the system has been produced and is in operational use may be costly in terms of possible modifications for corrective action. In addition, the incorporation of design changes on a continuing basis without the proper controls may be costly from the standpoint of system support. In essence, there must be a well-planned program approach, with the proper controls, in order to ensure a total integrated system configuration in the end.

QUESTIONS AND PROBLEMS

1. Describe the "checks" and "balances" in the design process (as you see them).
2. How is design review and evaluation accomplished? Why is it important relative to meeting system engineering objectives?
3. What is included in the establishment of a "functional" baseline? "allocated" baseline? "product" baseline? Why is baseline management important?
4. Select a system of your choice, and construct a sequential flow diagram of the overall system development process. Identify the major tasks in system development, and develop a plan/schedule of formal design reviews. Briefly describe what is covered in each.
5. Identify some of the benefits derived through formal design review. Describe some of the concerns.
6. In developing an agenda in preparing for a formal design review, what considerations must be addressed in the selection of items to be covered in the review process? How are review and evaluation criteria identified? Describe the steps and resources required in preparing for the design review.
7. How are technical performance measures (TPMs) considered in the design review process?
8. In the event that a deficiency is identified during design review, what steps are required for corrective action?
9. How are design changes initiated? How are priorities established?
10. How are design changes implemented? Identify the steps involved in system modification.

11. Describe the functions of the CCB.
12. What is "Configuration Management" (CM)? Define "Configuration Identification" (CI) and "Configuration Status Accounting" (CSA).
13. How does Configuration Management (CM) relate to system engineering? Why is it important? What is likely to occur if Configuration Management practices are not followed?