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IEEE Std 1220™-2005
(Revision of
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IEEE Standard for Application and Management of the Systems Engineering Process

IEEE Computer Society

Sponsored by the
Software and Systems Engineering Standards Committee

IEEE

3 Park Avenue, New York, NY10016-5997, USA

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IEEE Standard for Application and Management of the Systems Engineering Process

Sponsor

Software and Systems Engineering Standards Committee
of the
IEEE Computer Society

Approved 20 March 2005

IEEE-SA Standards Board

Abstract: The interdisciplinary tasks, which are required throughout a system's life cycle to transform customer needs, requirements, and constraints into a system solution, are defined. In addition, the requirements for the systems engineering process and its application throughout the product life cycle are specified. The focus of this standard is on engineering activities necessary to guide product development while ensuring that the product is properly designed to make it affordable to produce, own, operate, maintain, and eventually to dispose of, without undue risk to health or the environment.
Keywords: acquire, analysis, architecture, building block, design, development, component, hardware, interface, life cycle processes, software, supplier, synthesis, system, system life cycle, systems engineering, technical management, validation, verification

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Introduction

This introduction is not part of IEEE Std 1220-2005, IEEE Standard for Application and Management of the Systems Engineering Process.

History

IEEE Std 1220 was initially published in January 1995 as a trial-use standard. After the two-year trial-use period, the document was revised and balloted in 1998 for full publication in 1999.

The International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) formed a joint body to collaborate in fields of mutual interest for worldwide standardization efforts. ISO/IEC established a joint technical committee for international standards development, ISO/IEC JTC 1, Information Technology. In parallel with IEEE Std 1220 developments, ISO/IEC JTC 1, Subcommittee 7 (SC7), Software and Systems Engineering, began generation of ISO/IEC 15288:2002 [B3].[a] ISO/IEC 15288:2002 provides a framework based on a broad set of processes that an organization or project may employ to perform or manage the stages of a system's life cycle. ISO/IEC 15288:2002 supports the full life cycle of systems—from conception through retirement—as well as the acquisition and supply of systems.

It is the intent of ISO/IEC 15288:2002 to establish standard life cycle process descriptions suitable for most man-made systems. As such, the processes and terminology of the standard are defined at an appropriately high level of abstraction. ISO/IEC 15288:2002 does not prescribe, nor provide, detailed system engineering process definitions or methods and procedures to address detail process requirements derived from the application of this standard. ISO/IEC TR 19760:2003 [B4], the companion guide for ISO/IEC 15288:2002, lists several standards, including IEEE Std 1220-1998, that cover engineering disciplines at a lower-tier level and are suitable for implementation with ISO/IEC 15288:2002.

This revision of IEEE Std 1220-1998 is a result of an ongoing harmonization of the standards of the IEEE Computer Society's Software and Systems Engineering Standards Committee (S2ESC) and the corresponding international standards committee, ISO/IEC JTC1/SC7. This initial alignment of IEEE Std 1220-1998 with ISO/IEC 15288:2002 was developed in cooperation with ISO/IEC JTC1/SC7 and included participation of the International Council on Systems Engineering (INCOSE). The next step towards harmonization of these two standards would be the submission of IEEE Std 1220-2005 for a "fast-track" ballot with ISO/IEC JTC1/SC7 followed by a coordinated revision.

The IEEE Computer Society has embraced the top-level framework provided by ISO/IEC 15288:2002 and has adopted ISO/IEC 15288 as IEEE Std 15288™-2004. The IEEE Computer Society offered to align IEEE Std 1220-1998 with ISO/IEC 15288:2002 to facilitate the joint use of the two standards to manage system engineering efforts. The purpose of this revision of IEEE Std 1220-1998 is to identify key similarities and differences in the two standards and demonstrate how they can be used together while minimizing the impact of ISO/IEC 15288:2002 on current IEEE Std 1220-1998 users who may not employ ISO/IEC 15288:2002.

The key differences between this version of the standard, IEEE Std 1220-2005, and the 1998 version are as follows:

a) Inclusion of explanations regarding key differences between IEEE Std 1220-1998 and ISO/IEC 15288:2002 in areas such as terminology and structure

b) Minimal adjustments to some IEEE Std 1220-1998 terms and definitions for alignment with ISO/IEC publication requirements

c) Clarification of the distinction between requirements and recommendations of the standard

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d) Update of the conformance clause for alignment with IEEE standards style and rules

Most of the IEEE Std 1220-1998 content remains the same in this version. Explanations to facilitate use of IEEE Std 1220 with ISO/IEC 15288:2002 are contained in a new Annex C.

Purpose

This standard defines the requirements for an enterprise's total technical effort related to development of products (including computers and software) and processes that will provide life cycle support (sustain and evolve) for the products. It prescribes an integrated technical approach to engineering a system and requires the application and management of the systems engineering process throughout a product life cycle. The systems engineering process is applied recursively to the development or incremental improvement of a product to satisfy market requirements and to simultaneously provide related life cycle processes for product development, manufacturing, test, distribution, operation, support, training, and disposal.

The concept of systems engineering embodied in this standard provides an approach for product development in a system context. It is not meant to describe what an organizational entity called systems engineering does or a job position for which a systems engineer is responsible. Rather, it encompasses what all organizational entities and all enterprise and project personnel must accomplish to produce a quality, competitive product that will be marketable, will provide an acceptable return on investment to the enterprise, will achieve stakeholder satisfaction, and will meet public expectations.

The fundamental systems engineering objective is to provide high-quality products and services, with the correct people and performance features, at an affordable price, and on time. This involves developing, producing, testing, and supporting an integrated set of products (hardware, software, people, data, facilities, and material) and processes (services and techniques) that is acceptable to stakeholders, satisfies enterprise and external constraints, and considers and defines the processes for developing, producing, testing, handling, operating, and supporting the products and life cycle processes. This objective is achieved by simultaneous treatment of product and process content to focus project resources and design decisions for the establishment of an effective system design. This involves an integrated handling of all elements of a system, including those related to manufacturing, test, distribution, operations, support, training, and disposal.

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IEEE Standard for Application and Management of the Systems Engineering Process

1. Overview

1.1 Scope

This standard defines the interdisciplinary tasks that are required throughout a system's life cycle to transform stakeholder needs, requirements, and constraints into a system solution. This standard is intended to guide the development of systems for commercial, government, military, and space applications. The information applies to a project within an enterprise that is responsible for developing a product design and establishing the life cycle infrastructure needed to provide for life cycle sustainment.

This standard specifies the requirements for the systems engineering process (SEP) and its application throughout the product life cycle. It does not attempt to define the implementation of each system life cycle process, but addresses the issues associated with defining and establishing supportive life cycle processes early and continuously throughout product development. In addition, the standard does not address the many cultural or quality variables that should be considered for successful product development. The standard focuses on the engineering activities necessary to guide product development while ensuring that the product is properly designed to make it affordable to produce, own, operate, maintain, and eventually to dispose of, without undue risk to health or the environment.

The requirements of this standard are applicable to new products as well as incremental enhancements to existing products. It applies to one-of-a-kind products, such as a satellite, as well as products that are mass-produced for the consumer marketplace. The requirements of this standard should be selectively applied for each specific system-development project. The role of systems engineering within the enterprise environment is described in Annex A.

The content of this standard describes an integrated approach to product development, which represents the total technical effort for the following:

a) Understanding the environments and the related conditions in which the product may be utilized and for which the product should be designed to accommodate

b) Defining product requirements in terms of functional and performance requirements, quality factors, usability, producibility, supportability, safety, and environmental impacts

c) Defining the life cycle processes for manufacturing, test, distribution, support, training, and disposal, which are necessary to provide life cycle support for products

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1.2 Purpose

The purpose of this document is to provide a standard for managing a system from initial concept through development, operations, and disposal. The inclusion of computers and associated software in today's products has made the need to engineer each of those products as a total system more acute. The human, physical, and software components should all be addressed to optimize overall system performance.

This standard, IEEE Std 1220-2005, may be used in conjunction with ISO/IEC 15288:2002 [B3].[1] This standard generally prescribes more detailed systems engineering process and management requirements that complete or complement the process activities described in ISO/IEC 15288:2002. However, ISO/IEC 15288:2002 provides additional process definition and guidance that supports life cycle model definition and application of the systems engineering process across a system's life cycle.

1.3 How to use this standard

1.3.1 Conformance

Normative provisions of this standard, which are indicated by a "shall" statement, are requirements to claim conformance to this standard. Provisions that are indicated by a "should" statement are recommendations. An enterprise that desires to claim conformance with this standard demonstrates conformance by defining and implementing procedures for accomplishing all normative provisions.

1.3.2 Recommendations and tailoring

The enterprise should also incorporate select recommended and optional provisions into their procedures and should ensure that each project within the enterprise complies with these procedures.

Clause 4 provides some normative provisions and recommendations for implementing systems engineering within an enterprise or on a project. Normative provisions of Clause 4 include the development and maintenance of enterprise policies and procedures. Enterprise policies and procedures that describe the application of the systems engineering process (SEP) throughout a project life cycle typically provide the basis for project-specific application of the enterprise's SEP. Therefore, it is expected that an enterprise would establish and maintain such policies and procedures.

Clause 6 defines the SEP, which is accomplished iteratively to define system products and life cycle processes. Thus, the initial provision that defines each subprocess (requirements analysis, functional analysis, etc.) includes a "shall" statement to ensure that an enterprise's SEP addresses each subprocess and the tasks for performance of that subprocess. The remaining subclauses, when specified within the definition of a subprocess, are recommended to provide flexibility in adapting the subprocess and the task definitions of the SEP for the purposes and typical system engineering efforts of the enterprise. Clause 6 describes the recommended approach to project tailoring of the enterprise SEP, which would be applied for any particular project iteration of the SEP as described in Clause 5.

The initial provision of Clause 5 contains a "shall" statement to ensure that the project addresses application of the SEP throughout the system life cycle. The remaining provisions under Clause 5 describe recommended and optional activities that a project commonly performs when applying the SEP during each stage of a typical system life cycle. The recommended and optional activities of Clause 5 should be considered by the project during tailoring of the enterprise SEP for any particular iteration of the SEP throughout the system life cycle. This approach provides the project with the flexibility needed to address different levels of system development and appropriate rigor of SEP application throughout various system life cycle stages.

[1]The numbers in brackets correspond to those of the bibliography in Annex D.

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1.3.3 System paradigm

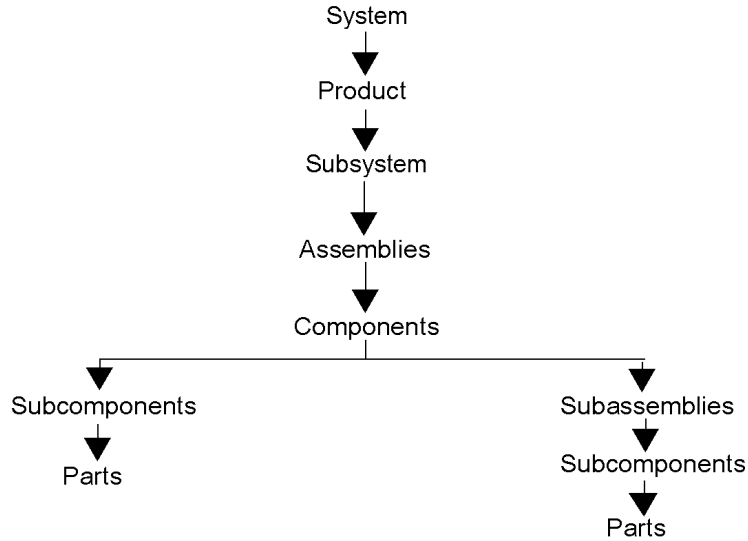
The description of the SEP, and its application throughout the life cycle, demands the use of a system paradigm to aid the presentation of this material. The terms used to support this paradigm are defined in Clause 3. As enterprises and projects gain familiarity with the paradigm, they may substitute more familiar terms that are applicable to their industry or business practices. The system paradigm is the foundation of this standard and is described in the following subclauses to support the different uses of the term system.

On a large scale, there are biological systems, ecological systems, weather systems, solar systems, etc. Thus, a system can be viewed as an element of a larger system, and the challenge is to understand the boundary of the system, which is the focus of the development effort, and the relationships and interfaces between this system and other systems. The focus of this standard is product-oriented systems such as the automobile, the airplane, or information systems.

1.3.3.1 Hierarchy of system elements

A system is typically composed of related elements (subsystems and components) and their interfaces. Additionally, elements include the people required to develop, produce, test, distribute, operate, support, or dispose of the element's products, or to train those people to accomplish their role within the system. Figure 1 provides a hierarchy of names for the elements making up a system. This generic system hierarchy is a key concept within this standard because it ties the system architectures, specification and drawing trees, system breakdown structure (SBS), technical reviews, and configuration baselines together. Many elements within the system hierarchy can be considered a "system" by the classical definition, but actually represent subsystems within the system hierarchy. Likewise, the life cycle processes represent subsystems within the overall system hierarchy.

Complex components represent system elements that are composed of hardware, software, and/or humans, which are recognizable in terms of life cycle process (how to design, test, produce, support, etc., is known), and the domain-specific engineering team assumes responsibility for the development of the complex components. This is a judgment call—complex components may demand the rigors of the SEP or may be well suited for component development teams.



Elements of the system may include hardware, software, and humans dependent on the system definition.

Figure 1—Hierarchy of elements within a system

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The human elements are integral to the systems hierarchy and may be present at any level. The human elements are not identified in the system hierarchy since the intent of the hierarchy is to identify the system element for which the system is being defined, and the human/system integration issues should be addressed in terms of the human's role in operating, producing, supporting, etc.

The hierarchy of elements within a system is provided to illustrate that systems may be comprised of other systems (subsystems), which represent complex elements for which no existing design solution or supplier can be identified. The number of levels of subsystem or complex components is dependent on the complexity of the system being developed. The SEP is applied at each level in the system hierarchy for which the system element is a complex item for which no available design solution, or existing producer, can be identified. Once a system element can be identified with a hardware, software, or human element, the discipline-specific design methodologies are utilized to design the system element.

1.3.3.2 Building block structure

The basic building blocks of a system are depicted in Figure 2—the system, its related product(s), the life cycle processes required to support the products, and the subsystems that make up the product(s). Each life cycle process—development, manufacturing, test, distribution, operation, support, training, or disposal—is itself like a system in that products should be developed to fulfill the purpose of the life cycle process. For example, a product should be manufactured. Manufacturing is a life cycle process. The products associated with the manufacturing life cycle process include special equipment, tools, facilities, and production processes and procedures. The products that make up life cycle processes may also require life cycle sustainment in that they may be required to be developed, tested, manufactured, distributed, operated, supported, trained, and disposed of.

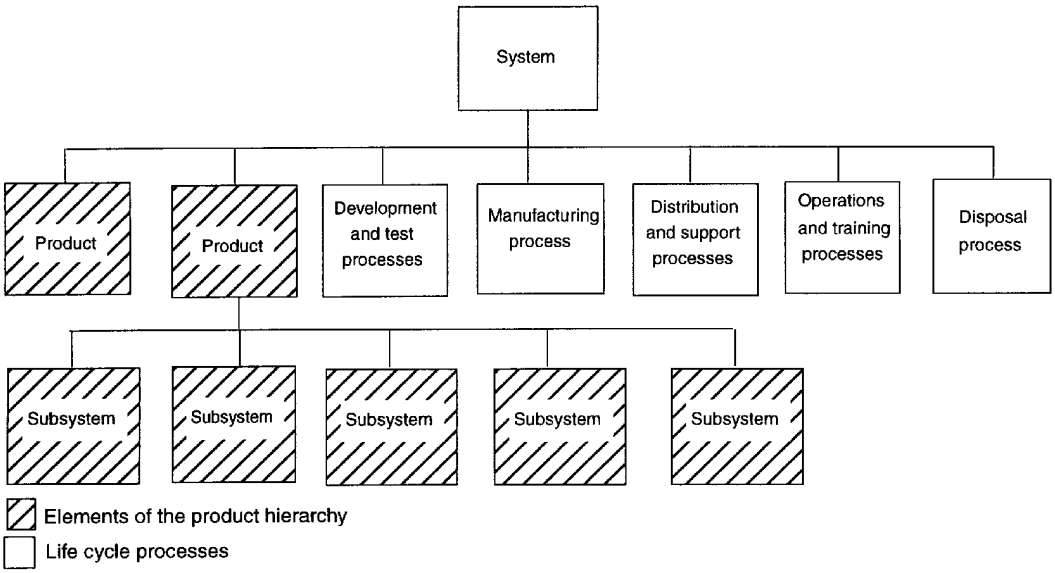

Figure 2—Basic building blocks of a system

1.3.3.3 Product and life cycle process definition

Figure 3 depicts the life cycle processes, eight essential functional processes that may be necessary to provide total consumer satisfaction and meet public acceptance. Once the need for a life cycle process is identified, the life cycle process is treated as a system, and the SEP is applied to define, design, and establish the life cycle process and the supporting products and processes, to maintain the life cycle process in an operational condition.

a) *Development.* The planning and execution of system and subsystem definition tasks required to evolve the system from stakeholder needs to product solutions and their life cycle processes.

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b) *Manufacturing.* The tasks, actions, and activities for fabrication and assembly of engineering test models and brass-boards, prototypes, and production of product solutions and their life cycle process products.

c) *Test*

1) The tasks, actions, and activities for planning for evaluation and conducting evaluation of synthesis products against the functional architecture or requirements baseline, or the functional architecture against the requirements baseline.

2) The tasks, actions, and activities for evaluating the product solutions and their life cycle processes to measure specification conformance or stakeholder satisfaction.

d) *Distribution.* The tasks, actions, and activities to initially transport, deliver, assemble, install, test, and check out products to effect proper transition to users, operators, or consumers.

e) *Operations.* The tasks, actions, and activities that are associated with the use of the product or a life cycle process.

f) *Support.* The tasks, actions, and activities to provide supply, maintenance, and support material and facility management for sustaining operations.

g) *Training.* The measurable tasks, actions, and activities (including instruction and applied exercises) required to achieve and maintain the knowledge, skills, and abilities necessary to efficiently and effectively perform operations, support, and disposal throughout the system life cycle. Training is inclusive of the tools, devices, techniques, procedures, and materials developed and employed to provide training for all required tasks.

h) *Disposal.* The tasks, actions, and activities to ensure that disposal or recycling of destroyed or irreparable consumer and life cycle processes and by-products comply with applicable environmental regulations and directives.

A typical system is composed of products developed by the enterprise or by suppliers/subcontractors. Each supplier/subcontractor considers its product as part of its system. The organization that purchases these products for integration into a higher-level system should refer to these products as subcomponents, components, complex components, or subsystems, depending on the significance of the element in contributing to the system's performance, functionality, and costs.

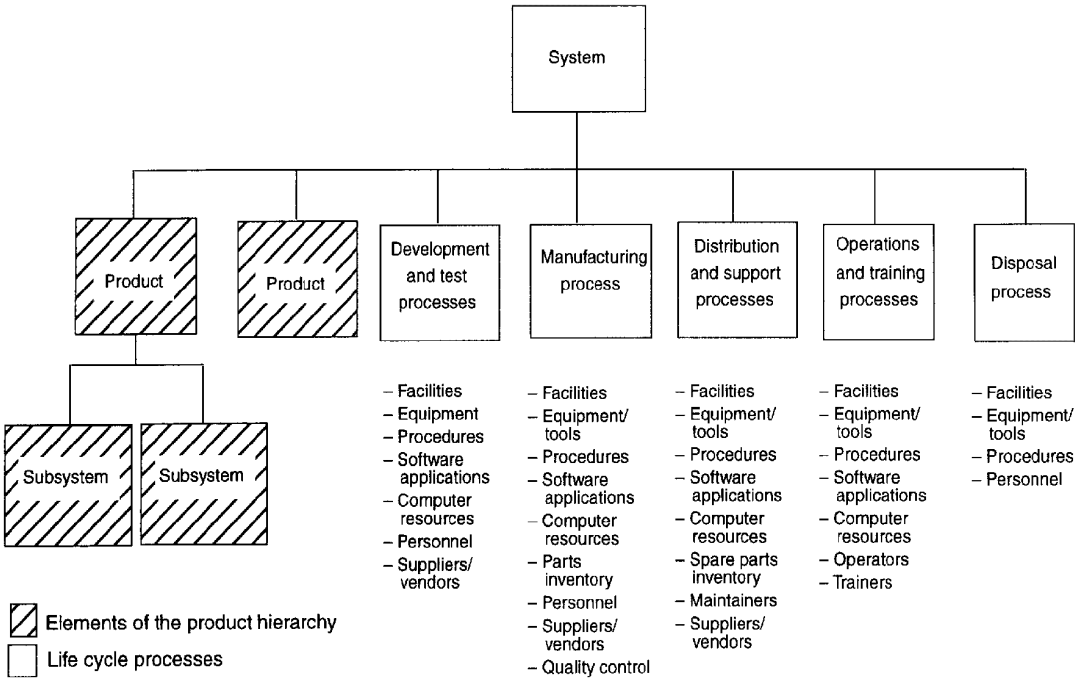

Figure 3—Life cycle process definition

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The design of the products and life cycle processes should consider the human as an element of the system in terms of operators, maintainers, manufacturing personnel, training personnel, etc., for the purpose of understanding the human/system integration issues and ensuring that the system products are producible, maintainable, and usable, and that the system processes are effectively established to ensure production quality levels and reduce overall ownership cost. Thus, Figure 3 depicts the human elements associated with the system products and processes. The operational process addresses the operation of the product(s) and aids in the identification of operational procedures and human cognitive and anthropomorphic considerations necessary to ensure system usability.

The definitions of system elements are generated by activities of the SEP. This process is described in detail in Clause 6. The SEP is used during each level of development to structure systems engineering activities that identify technical requirements and desired system behaviors, and synthesize the system design.

1.4 Organization of this standard

— Clause 1 provides the scope, purpose, and organization of this standard.

— Clause 2 provides the normative references applicable to this document.

— Clause 3 establishes the meaning of terms and acronyms, as used in this standard.

— Clause 4 establishes requirements for planning and implementing an effective systems engineering capability within an enterprise.

— Clause 5 provides a description of the application of the SEP through system definition, subsystem definition, production, and support.

— Clause 6 provides the detailed tasks of the SEP to be tailored and performed to develop product solutions and their supporting life cycle processes.

— Annex A discusses the SEP as the total technical effort responsible for establishing the product design and life cycle support products within an enterprise.

— Annex B provides a template to help an enterprise prepare a systems engineering management plan.

— Annex C discusses some of the key differences between IEEE Std 1220 and ISO/IEC 15288:2002 [B3].

— Annex D provides bibliographic references.

2. Normative references

The following referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 610.12™-1990 (Reaff 2002), IEEE Standard Glossary of Software Engineering Terminology.[2]

[2]IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

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3. Definitions and acronyms

3.1 Definitions

The definitions listed below establish meaning in the context of this standard. If there is a conflict between the terms in the references and this standard, then the definitions provided here should take precedence as they apply only to the practices and requirements of this standard.

3.1.1 acquirer: The stakeholder that acquires or procures a product or service from a supplier.

NOTE 1—Other terms commonly used for an *acquirer* are *buyer, customer,* and *purchaser.* The acquirer may at the same time be the owner, user, or operating organization.[3]

NOTE 2—*Customer* is a broader reference than *acquirer, operator,* or *user* and includes those roles as well as others.

NOTE 3—Adapted from ISO/IEC 15288:2002 [B3].

3.1.2 agreement: The mutual acknowledgement of terms and conditions under which a working relationship is conducted.

NOTE—See ISO/IEC 15288:2002 [B3].

3.1.3 allocation: The decision to assign a function or decision to hardware, software, or humans.

NOTE—Allocation may be made entirely to one of these three system element types or to some combination to be resolved upon further functional decomposition.

3.1.4 baseline: A specification or product that has been formally reviewed and agreed upon, that thereafter serves as the basis for further development, and that can be changed only through formal change control procedures.

NOTE—See ISO/IEC 15288:2002 [B3].

3.1.5 constraint: A limitation or implied requirement that constrains the design solution or implementation of the SEP and is not changeable by the enterprise.

NOTE—A constraint is generally nonallocable.

3.1.6 customer: Organization or person that receives a product. Examples: Consumer, client, end user, retailer, beneficiary, and purchaser.

NOTE 1—A customer can be internal or external to the organization.

NOTE 2—See ISO 9000:2000 [B1].

NOTE 3—*Customer* is a broader reference than *acquirer, operator,* or *user* and includes those roles as well as others.

3.1.7 design architecture: An arrangement of design elements that provides the design solution for a product or life cycle process intended to satisfy the functional architecture and the requirements baseline.

3.1.8 design characteristic: The design attributes or distinguishing features that pertain to a measurable description of a product or process.

3.1.9 design to cost: Cost goals for the production cost (design-to unit production cost) and life cycle cost (design-to life cycle cost) of the products used to make the design converge on cost targets.

NOTE—Cost goals should be treated with the same attention as any other performance parameter.

[3]Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

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3.1.10 effectiveness analysis: An analysis of how well a design solution will perform or operate given anticipated operational scenarios.

3.1.11 effectiveness assessment: The evaluation of the design solution with respect to manufacturing, test, distribution, operations, support, training, environmental impact, cost-effectiveness, and life cycle cost.

3.1.12 end item: An entity (hardware equipment, software equipment, data, facilities, material, services, and/or techniques) identified with an element of the SBS.

3.1.13 enterprise: The organization that performs specified tasks.

NOTE—When a project that is in a nonconforming enterprise applies the standard directly, references to "enterprise" should be understood to mean the project.

3.1.14 facility: The physical means or equipment for facilitating the performance of an action, e.g. buildings, instruments, tools.

NOTE—See ISO/IEC 15288:2002 [B3].

3.1.15 functional architecture: An arrangement of functions and their subfunctions and interfaces (internal and external) that defines the execution sequencing, conditions for control or data flow, and the performance requirements to satisfy the requirements baseline.

3.1.16 functional requirement: A statement that identifies what a product or process must accomplish to produce required behavior and/or results.

3.1.17 human systems engineering: The activities involved throughout the system life cycle that address the human element of system design (including usability, measures of effectiveness, measures of performance, and total ownership cost) and that include the definition and synthesis of manpower, personnel, training, human engineering, health hazards, and safety issues.

3.1.18 integrated repository: A repository for storing all information pertinent to the SEP to include all data, schema, models, tools, technical management decisions, process analysis information, requirement changes, process and product metrics, and trade-offs.

3.1.19 interface specification: The description of essential functional, performance, and design requirements and constraints at a common boundary between two or more system elements.

NOTE—This includes interfaces between humans and hardware or software, as well as interfaces between humans themselves.

3.1.20 life cycle: The system or product evolution initiated by a perceived stakeholder need through the disposal of the products.

3.1.21 life cycle cost: The total investment in product development, manufacturing, test, distribution, operation, support, training, and disposal.

3.1.22 life cycle model: A framework of processes and activities concerned with the life cycle, which also acts as a common reference for communication and understanding.

NOTE—See ISO/IEC 15288:2002 [B3].

3.1.23 measure of effectiveness (MOE): The metrics by which an acquirer will measure satisfaction with products produced by the technical effort.

3.1.24 measure of performance (MOP): An engineering performance measure that provides design requirements that are necessary to satisfy an MOE.

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NOTE—There are generally several measures of performance for each MOE.

3.1.25 operator: An individual or an organization that contributes to the functionality of a system and draws on knowledge, skills, and procedures to contribute the function.

NOTE 1—The role of operator and the role of user may be vested, simultaneously or sequentially, in the same individual or organization.

NOTE 2—An individual operator combined with knowledge, skills, and procedures may be considered as an element of the system.

NOTE 3—*Customer* is a broader reference than *acquirer, operator,* or *user* and includes those roles as well as others.

NOTE 4—Adapted from ISO/IEC 15288:2002 [B3].

3.1.26 performance requirement: The measurable criteria that identifies a quality attribute of a function or how well a functional requirement must be accomplished.

3.1.27 requirement: A statement that identifies a product or process operational, functional, or design characteristic or constraint, which is unambiguous, testable or measurable, and necessary for product or process acceptability (by consumers or internal quality assurance guidelines).

3.1.28 specification: A document that fully describes a design element or its interfaces in terms of requirements (functional, performance, constraints, and design characteristics) and the qualification conditions and procedures for each requirement.

3.1.29 specification tree: A hierarchy of specification elements and their interface specifications that identify the elements and the specifications related to design elements of the system configuration that are to be controlled.

3.1.30 stage: A period within the life cycle of a system that relates to the state of the system description or the system itself.

NOTE 1—Stages relate to major progress and achievement milestones of the system through its life cycle.

NOTE 2—Stages may be overlapping.

NOTE 3—See ISO/IEC 15288:2002 [B3].

3.1.31 stakeholder: A party having a right, share, or claim in a system or in its possession of characteristics that meet that party's needs and expectations.

NOTE 1—*Stakeholder* is a broader reference than *customer, acquirer, operator,* or *user* and includes those roles as well as others.

NOTE 2—Adapted from ISO/IEC 15288:2002 [B3].

3.1.32 state: A condition that characterizes the behavior of a function/subfunction or element at a point in time.

3.1.33 supplier: An organization or an individual that enters into an agreement with the acquirer for the supply of a product or service.

NOTE—See ISO/IEC 15288:2002 [B3].

3.1.34 system: A set or arrangement of elements [people, products (hardware and software) and processes (facilities, equipment, material, and procedures)] that are related, and whose behavior satisfies operational needs and provides for the life cycle sustainment of the products.

3.1.35 system architecture: The composite of the design architectures for products and their life cycle processes.

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3.1.36 system breakdown structure (SBS): A hierarchy of elements, related life cycle processes, and personnel used to assign development teams, conduct technical reviews, and to partition out the assigned work and associated resource allocations to each of the tasks necessary to accomplish the objectives of the project.

NOTE—The SBS can be used as a basis for cost-tracking and control.

3.1.37 system effectiveness: A measurement of the ability of a system to satisfy its intended operational uses as a function of how the system performs under anticipated environmental conditions, and the ability to produce, test, distribute, operate, support, train, and dispose of the system throughout its life cycle.

3.1.38 trade-off analysis: An analytical evaluation of design options/alternatives against performance, design-to-cost objectives, and life cycle quality factors.

3.1.39 user: Individual who or group that benefits from a system during its utilization.

NOTE 1—The role of user and the role of operator may be vested, simultaneously or sequentially, in the same individual or organization.

NOTE 2—*Customer* is a broader reference than *acquirer, operator,* or *user* and includes those roles as well as others.

NOTE 3—Adapted from ISO/IEC 15288:2002 [B3].

3.2 Acronyms

BIT built-in test

FAIT fabrication, assembly, integration, and test

FIT fault-isolation test

FMEA failure modes and effects analysis

IPT integrated product team

MOE measure of effectiveness

MOP measure of performance

SBS system breakdown structure

SEMS systems engineering master schedule

SEP systems engineering process

TPM technical performance measure

4. General requirements

The enterprise shall plan, implement, and control an integrated technical effort in accordance with this standard to develop a total system solution that is responsive to market opportunities, specified stakeholder requirements, enterprise objectives, and external constraints. Performance of the activities listed in items a) through f) are typically necessary to meet this goal.

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To meet this goal, the enterprise should

a) Plan, conduct, and manage a fully integrated technical effort necessary to satisfy the general requirements of this document, as tailored for the specific project.

b) Apply the SEP for each level of system.

c) Control progress through the conduct of the following:

   1) Technical reviews following each level of development

   2) Risk management

   3) Data management

   4) Interface management

   5) Configuration management

   6) Performance-based progress measurement

d) Generate models and prototypes to support trade-off.

e) Generate an integrated data package, which ensures that the product can be produced, tested, delivered, operated, supported, and properly disposed of.

f) Capture the outputs from all technical activities in an integrated repository.

Specific requirements and recommendations are provided in other clauses of this standard.

4.1 Systems engineering process

The enterprise shall apply the normative provisions of the SEP, described in Clause 6 and illustrated in Figure 4, to produce the specifications and baselines and related products, as described in Clause 5. The SEP is a generic problem-solving process that provides the mechanisms for identifying and evolving the product and process definitions of a system. The SEP applies throughout the system life cycle to all activities associated with product development, verification/test, manufacturing, training, operation, support, distribution, disposal, and human systems engineering. Figure 4 depicts the subprocesses of the SEP and shows how they iterate to produce a consistent set of requirements, functional arrangements, and design solutions. The subprocesses, tasks, and activities of the SEP are described in detail in Clause 6.

4.2 Policies and procedures for systems engineering

The enterprise shall develop and maintain policies and procedures for governing the conduct of the SEP. These policies and procedures specify requirements for the planning, implementation, and control of product and process development and human/systems integration. These policies and procedures should establish the enterprise's paradigm for systems engineering from which training can be based and project-specific activities can be tailored and accomplished. Enterprise policies and procedures should address the following:

a) Application of the SEP throughout a project life cycle

b) Preparation and approval of a systems engineering management plan

c) Preparation and approval of a systems engineering master schedule (SEMS) and systems engineering detailed schedule

d) Preparation and approval of the integrated data package

e) Monitoring and reporting technical progress of the project

f) Preparation for, and conduct of, technical reviews

g) Contents and maintenance of an integrated repository

h) Continuous improvement of products and processes

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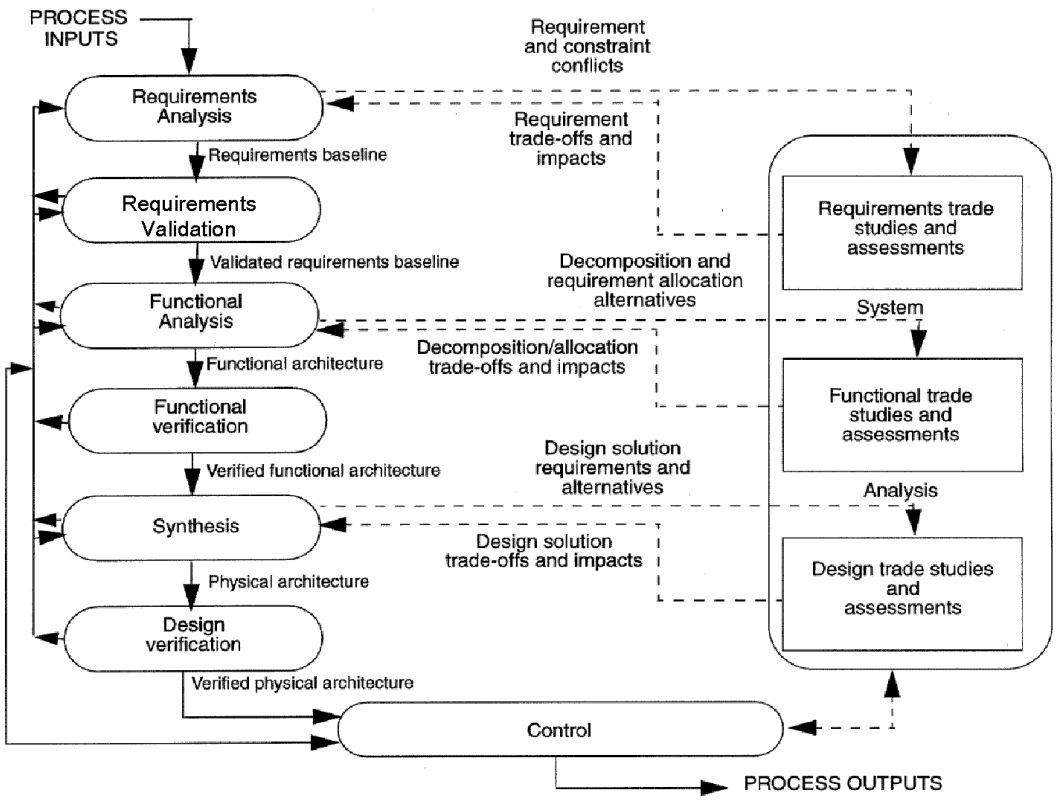

Figure 4—Systems engineering process (SEP)

4.3 Planning the technical effort

The project shall prepare and implement the technical plans and schedules necessary to guide the project toward accomplishment of its objectives and proper conclusion. Given the project's authorization and objectives, the project should establish an engineering plan, a master schedule, and a detail schedule. The engineering plan should be the main planning document for all technical efforts and describe the tailored application of this standard. The master schedule, an event-based schedule, and the detail schedule, a calendar-based schedule derived from the master schedule, should address the development activities for the product, as well as supporting life cycle processes. The master schedule and detail schedule may be combined into a single engineering schedule. The project should establish plans for the technical effort in accordance with the following subclauses.

4.3.1 Engineering plan

The engineering plan shall be prepared and updated throughout the system life cycle to guide and control the technical efforts of the project. The engineering plan should reflect an integrated technical effort responsible for product development that addresses all factors associated with meeting system life cycle requirements. The engineering plan should reflect the contents identified in Annex B, which provides a generic outline and description of the contents for an engineering plan. If an evolutionary or incremental development strategy is to be pursued, the engineering plan should address the development strategy for initial product development and insertion of incremental capability and /or technology enhancements.

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4.3.2 Master schedule

The master schedule should be prepared and updated throughout the system life cycle to establish key events, their significant tasks, and the criteria by which completion of significant tasks are determined. A properly designed master schedule should allow for the scheduling of activities associated with tasks, allocation of resources, budget preparation, assignment of personnel, establishment of task start and end dates, and event completion criteria.

4.3.3 Detail schedule

The detail schedule should provide a calendar-based schedule of activities, tasks, and key events of the master schedule. The detail schedule should be used to track the progress of the technical effort. Detail schedule data should be used to construct a network of events, tasks, and activities to determine the critical path of the engineering efforts and to analyze variances to schedule.

4.3.4 Technical plans

Technical plans shall be prepared to supplement the engineering plan, as needed. Technical plans should be prepared by the engineering and technical specialty areas to which they apply and should be used to measure technical progress against the plans. Technical plans are typically prepared for risk management, configuration management, technical reviews, verifications, computer resources, manufacturing, maintenance, training, security, and human systems engineering.

4.4 Development strategies

The project should explore development strategies for developing the system and its capabilities (e.g., waterfall, incremental, evolutionary, and spiral). The capacity to change or enhance the product and life cycle processes should be designed into the system architecture to enable the cost-effective sustainment of the system throughout its life cycle. This design attribute should be established early in the system development [when identifying stakeholder requirements or constraints (see 6.1.1 and 6.1.2)] to provide a basis for planning each incremental development effort. Evolutionary development strategies should address approaches for managing the introduction of new technologies, evolving requirements, or enhancing product capabilities.

4.5 Modeling and prototyping

The project should determine and establish suitable models, simulations, or prototypes to support analysis and project decision making. Typical subjects of modeling, simulation, and prototyping include: requirements definition, analysis of the system architecture and design, and mitigation of identified risks. These simulations focus on ensuring that the final product satisfies market needs, requirements, and constraints. This effort supports the assessment of system functional and performance characteristics, producibility, supportability, environmental impact, and human systems engineering issues such as maintainability, usability, operability, and safety.

4.6 Integrated repository

The enterprise shall capture pertinent design data in a repository for the evolving integrated data package and to provide a shared resource for the exchange and reuse of technical information.

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4.6.1 Data

Pertinent data includes: the engineering plan; schedules; technical plans; functional, physical, and system architectures; rationale for design decisions; trade-off analyses accomplished, including recommendations and impacts; effectiveness assessments and their outcomes; risk assessments and handling options; sketches and drawings; engineering changes; specification trees; specifications and configuration baselines; operational environment; manpower, personnel, training, and human engineering requirements and specifications; archival data; technical objectives, requirements, constraints, interfaces, and risks; SBSs; design models; test results; metrics; and any other data that allow for traceability of requirements throughout the functional and design architectures.

4.6.2 Tools

The project shall maintain traceability between the versions of tools and the models, analysis results, and other outputs of tools, to ensure the ability to reproduce execution results supporting the SEP.

4.7 Integrated data package

The project shall generate an integrated data package that documents architecture and design information for the support of life cycle processes. The integrated data package should include the types of engineering data defined in Table 1, as required by the project. The initial content of the integrated data package should be defined early in the system life cycle, should consist of the classes of information identified in 4.7.1 through 4.7.4, and should evolve with each application of the SEP to provide more detail with each level of development.

4.7.1 Hardware

The integrated data package includes the technical design information that supports product manufacturing, assembly, and integration.

4.7.2 Software

The integrated data package includes the technical design information that supports software requirements, design, source code, verification and validation, build instructions, operation, and maintenance.

4.7.3 Life cycle processes

The integrated data package includes the technical design information for the life cycle processes and the special equipment specifications and baselines, software code listings, technical manuals, technical plans, facility drawings, and special tools related to manufacturing, verification, distribution, operations, support, training, and disposal.

4.7.4 Human

The integrated data package includes the information that supports the definition of the role of the humans who support the system life cycle. Example products include the human systems engineering plan, safety specifications, manpower, personnel, and training documentation; workspace arrangement drawings; interface design specifications and drawings; operational sequence diagrams; manual procedures; and models, simulations, or design databases.

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Table 1—Integrated data package content

An integrated data package includes, but is not limited to the following items:
A. Hardware 1) **Arrangement drawings**—document the relationship of the major subsystems or components of the system. 2) **Assembly drawings**—document the relationship of a combination of parts and subassemblies required to form the next higher indenture level of equipment or system. 3) **Connection drawings**—document the electrical connections of an installation or of its component devices or parts. 4) **Construction drawings**—document the design of buildings or structures. 5) **Product drawings**—an engineering drawing that documents configuration and configuration limitations, performance and test requirements, weight and space requirements, access clearances, pipe and cable attachments, support requirements, etc., to the extent necessary that an item may be developed or procured on the commercial market to meet the stated requirements. 6) **Detail drawings**—document complete end-item requirements for the subcomponent(s) delineated in the drawing. 7) **Elevation drawings**—document vertical projections of buildings and structures or profiles of equipment. 8) **Engineering drawings**—an engineering document that discloses, by means of pictorial or textual presentations, or a combination of both, the design and functional end-product requirements or design of an item. 9) **Installation drawings**—document general configuration and complete information necessary to install an item relative to its supporting structure or to associated items. 10) **Logic diagrams**—document, by means of graphic symbols or notations, the sequence and functions of logic circuitry and flows of sequences for operations, maintenance, test, and repair. 11) **Numerical control drawings**—document complete design and functional engineering and product requirements of an item to facilitate production by tape control means. 12) **Piping diagrams**—document the interconnection of components by piping, tubing, or hose, and when desired, the sequential flow of hydraulic fluids or pneumatic air in the system. 13) **Wire lists**—document a book-form drawing consisting of tabular data and instructions required to establish wiring connections within or between items. 14) **Schematic diagrams**—document, by means of graphical symbols, the electrical connections and functions of a specific circuit arrangement. 15) **Wiring and cable harness drawings**—document the path of a group of wires laced together in a specific configuration, so formed to simplify installation. 16) **Models, simulations, or design databases**—provide a physical, analytical, or digital representation of any of the items previously listed in items 1) through 15).
B. Software 1) **Software design documentation**—documents the software items architecture, design requirements, implementation logic, and data structures that provide a means of support. 2) **Software source code listings**—documents the actual source code instructions that represented the "as-built" implementation.

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Table 1—Integrated data package content *(continued)*

An integrated data package includes, but is not limited to the following items:
C. Human—documents cognitive, physical, and sensory characteristics of the humans who operate, maintain, and support the system throughout its life cycle that directly contribute to, or constrain, system performance and impact human-machine interfaces. 1) **Manpower, personnel, and training documentation**—documents the knowledge, skills, and abilities; training requirements; and availability of the humans who operate, maintain, and support the system throughout its life cycle. 2) **Workspace arrangement drawings**—document the relationship of humans that support each phase of the life cycle with major subsystems or components of the system. 3) **Interface design specifications and drawings**—document all interfaces between the humans that support the system life cycle and any aspect of the system, including human-human interfaces, human-hardware interfaces, and human-software interfaces. 4) **Operational sequence diagrams**—a graphical representation that documents the interaction between humans and other subsystems or components of the system in the performance of a task over time. 5) **Procedures**—document the actions that humans who support each phase of the life cycle perform to develop, produce, test, distribute, operate, support, and dispose of the system or its products, or to train humans to accomplish these actions. These procedures may be in the form of operational sequence diagrams, lists, or tables. 6) **Safety specifications**—document the equipment/system design features, performance specifications, and training that reduces the potential for human or machine errors or failures that cause injury or death within the constraints of operational effectiveness, time, and cost throughout the equipment/system life cycle.
D. Life cycle processes **Process product design architecture**—documents the design architecture for the life cycle process products related to development (systems engineering and integration), manufacturing, verification, distribution, support, training, and disposal. Products include equipment, software, people, facilities, processes, and services integral to a specific life cycle process.

4.8 Specification tree

The project shall generate a specification tree modeled after the design architecture appropriate to the level of development. The specification tree is composed of specification elements and interface specifications. Interface specifications document the interface requirements among interacting elements. System interface specifications define interfaces with external systems, platforms, and products. Subsystem interface specifications define interfaces among subsystems, including hardware-hardware, hardware-software, software-software, human-human, human-hardware, and human-software interfaces. The various specifications that define the elements of a fully developed system are shown in Figure 5. Since the project generally works on an element within a higher-level system, Figure 5 reflects how such an effort could be viewed in a system context. The specification tree is developed top down. The number of levels of a specification tree depends on the stage of the life cycle, as described in Clause 5. The lowest level of the specification tree is dependent upon the complexity of the design element and to what level the decision can be made to make, buy, or reuse the product associated with the specification. In the case of the humans who support the system throughout its life cycle, the decision is whether personnel with the appropriate knowledge, skills, and abilities are available, or what level of hiring, recruiting, or training needs to be performed. This could be at the subsystem level or any level down to the component level.

4.9 Drawing tree

The project shall generate a drawing tree to reflect the drawings associated with the hardware elements of the design architecture. This tree should resemble the specification tree of Figure 5.

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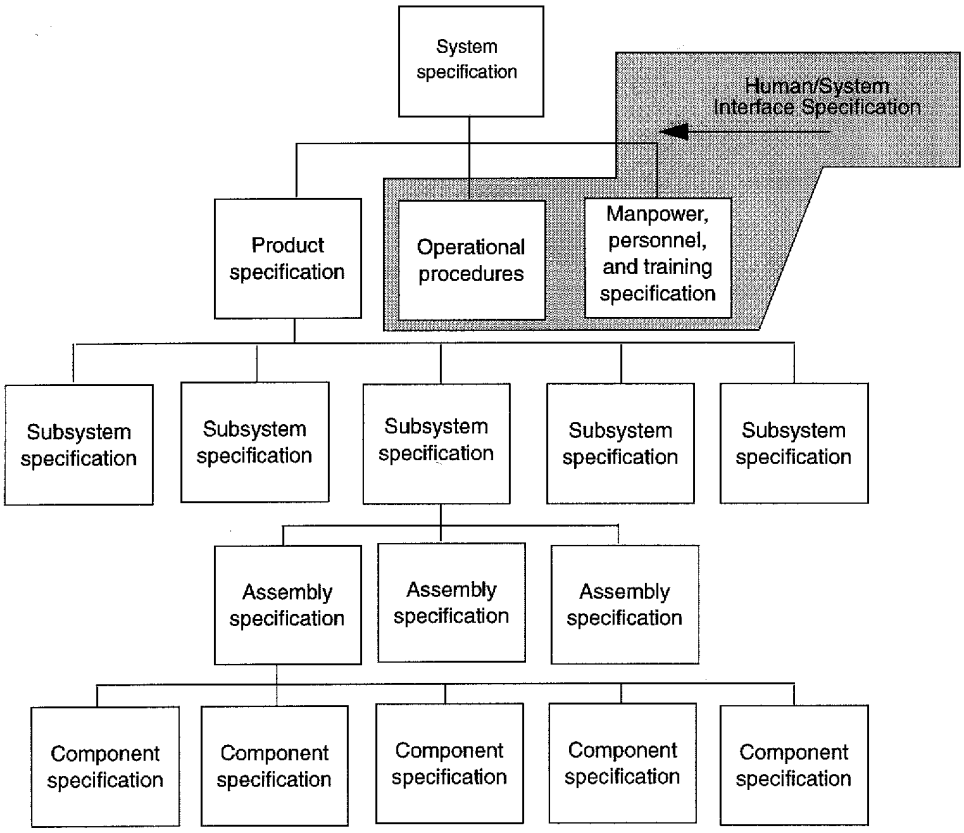

Figure 5—The specification tree

4.10 System breakdown structure

The project shall generate an SBS to depict the hierarchy of products and processes that comprise the system architecture. The SBS can be used by the project for development and control of planning packages and their conversion to work packages, sizing of work packages, configuration management, resource allocation, traceability of requirement changes, interface control, cost reporting, and event-based scheduling. The life cycle processes are assigned to the product, assembly, and if needed, the subassembly level of the SBS and the humans who support the life cycle. The manpower, personnel, and training specifications that define the knowledge, skills, abilities, availability, and training required for the humans who support the system, its subsystems, and components are developed to ensure that the system may be adequately operated and supported throughout its life cycle. The life cycle processes may be defined at each level of the SBS, as necessary, to provide life cycle sustainment for elements of the product. The various system elements and life cycle processes that make up an SBS for a representative fully developed system are shown in Figure 6. This figure reflects the three major levels of development of a system—system definition, preliminary design, and detailed design—through which a system evolves, as described in Clause 5.

4.11 Integration of the systems engineering effort

The project integrates the various inputs of the engineering and business specialties into the systems engineering effort to meet project objectives.

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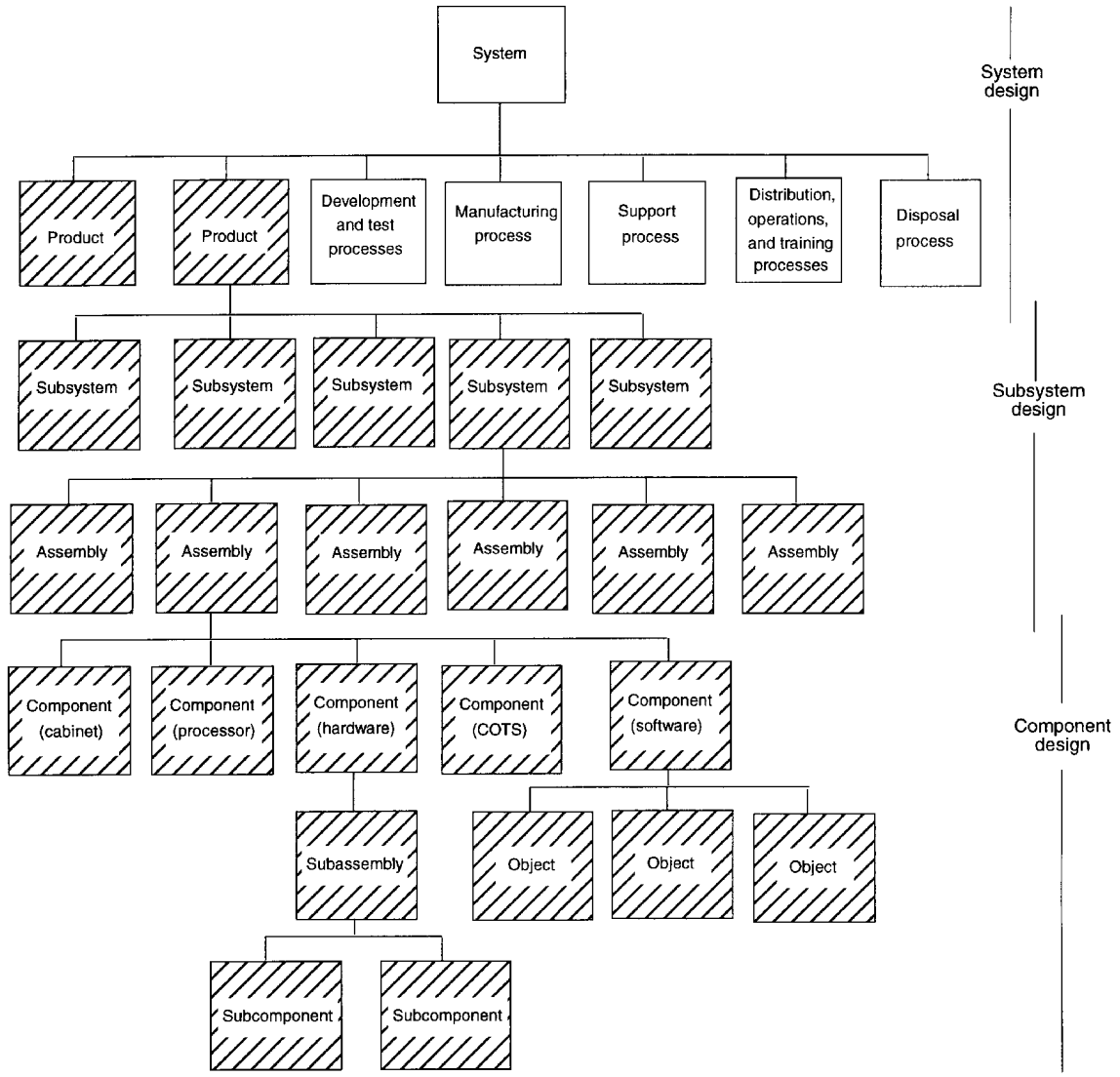

Figure 6—System breakdown structure

4.11.1 Concurrent engineering

The enterprise or project should integrate the concurrent design of products and their related life cycle processes. Concurrent engineering should integrate product and process development to ensure that the product(s) are producible, usable, and supportable. Computer-aided engineering tools should be used to support development and manufacturing, and should be integrated into the integrated repository.

4.11.2 Integrated teams

Integrated teams should be considered as a primary approach to organizing for efficiency and effectiveness. When integrated teams are utilized, the project should assign teams to specific elements of the SBS. Each team should prepare the required planning documents (engineering plan, master schedule, etc.) for the system element to which it is assigned; should be responsible for developing and satisfying the specifications and baselines associated with the element; and should complete the work outlined in tasking statements related to the element, including the technical reviews of Clause 5.

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