24

Processes for Engineering a System

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24.1 Introduction

In April 1995, the G47 Systems Engineering Committee of the Electronic Industries Alliance (EIA) chartered a working group to convert the interim standard EIA/IS 632 into a full standard. This full standard was developed and released in December 1998 as ANSI/EIA-632-1998.

The interim standard (IS), EIA/IS 632, was titled "Systems Engineering." The full standard was expanded in scope to include *all the technical processes for engineering a system*. It is intended to be a higher-level abstraction of the activities and tasks found in the IS version plus those other technical activities and tasks deemed to be essential to the engineering of a system.

This chapter describes the elements of these processes and related key concepts. The intended purpose is to give the reader of the standard some background in its development and to help other standards activities in developing their own standard. There is a paper that describes the evolution from an interim standard to the full standard [Martin, 1998].

This standard is intended to be a "top tier" standard for the *processes essential to engineering a system*. It is expected that there will be second- and third-tier standards that define specific practices related to certain disciplines (e.g., systems engineering, electrical engineering, software engineering) and industry domains (e.g., aircraft, automotive, pharmaceutical, building, and highway construction).

It is important to understand several things that are *not* covered by this standard:

1. It does *not* define what "systems engineering" is;
2. It does *not* define what a "systems engineer" is supposed to do; and
3. It does *not* define what a "systems engineering organization" is supposed to do.

24.2 Structure of the Standard

The standard is organized as shown below:

Clause 1	*Scope*
Clause 2	*Normative references*
Clause 3	*Definitions and acronyms*
Clause 4	*Requirements*
Clause 5	*Application context*
Clause 6	*Application key concepts*
Annex A	*Glossary*
Annex B	*Enterprise-based life cycle*
Annex C	*Process task outcomes*
Annex D	*Planning documents*
Annex E	*System technical reviews*
Annex F	*Unprecedented and precedented development*
Annex G	*Requirement relationships*

24.3 Role of the EIA 632 Standard

Implementation of the requirements of EIA 632 are intended to be through establishment of enterprise policies and procedures that define the requirements for application and improvement of the adopted processes from the standard. This is illustrated in Figure 24.1.

24.4 Heritage of EIA 632

Figure 24.2 shows the relationship between EIA 632 and other standards on systems engineering. Some of the key software engineering standards are shown for comparison since there has been an intimate relationship between the development of both types of standards. There has been much activity recently in unifying the processes contained in each.

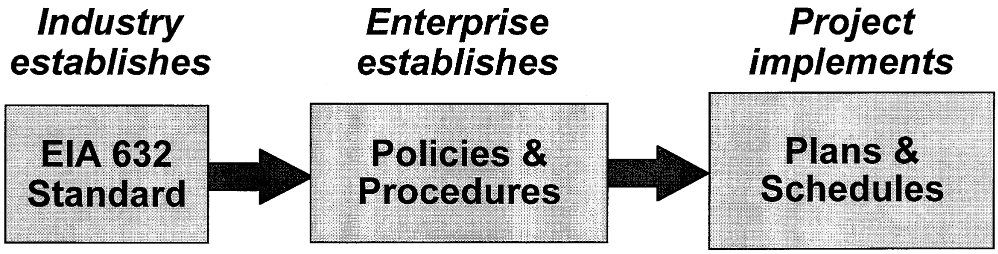


FIGURE 24.1 Role of the standard in relation to development projects. (Adapted from ANSI/EIA-632-1998. With permission.)

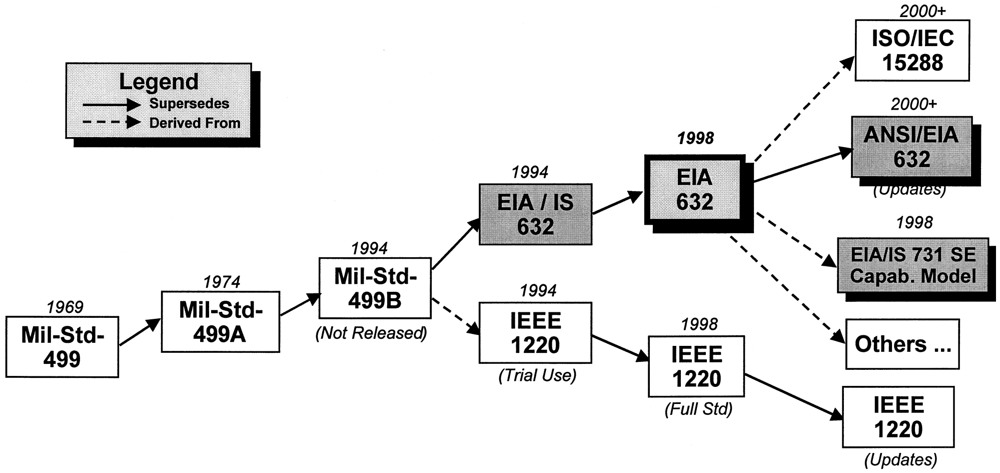


FIGURE 24.2 Heritage of systems engineering standards.

24.5 The Processes

Figure 24.3 shows the processes described in EIA 632 and their relationship to one another. Each enterprise will determine which of these processes are implemented by systems engineering personnel, and how they are allocated to the organizational elements of the enterprise and its functional disciplines.

24.5.1 Process Hierarchy

The processes for engineering a system are grouped into the five categories as shown in Figure 24.4. This grouping was made for ease of organizing the standard and is not a required structure for process implementation. Traditional systems engineering is most often considered to include two of these processes: Requirements Definition and Systems Analysis. Often, Planning and Assessment are included in what is called systems engineering management.

24.5.2 Technical Management Processes

Technical Management provides oversight and control of the technical activities within a development project. The processes necessary to accomplish this are shown in Figure 24.5.

24.5.3 Acquisition and Supply Processes

Acquisition and Supply provides the mechanism for a project to supply its own products to a customer or higher-level project and to acquire the necessary products for its own product development activities. The processes necessary to accomplish this are shown in Figure 24.6.

24.5.4 System Design Processes

System Design provides the activities for a project to define the relevant requirements for its product development effort and to design solutions that meet these requirements. The processes necessary to accomplish this are shown in Figure 24.7.

24.5.5 Product Realization Processes

Product Realization provides the activities for a project to implement the product designs and to transition these products to their place of use. The processes necessary to accomplish this are shown in Figure 24.8.

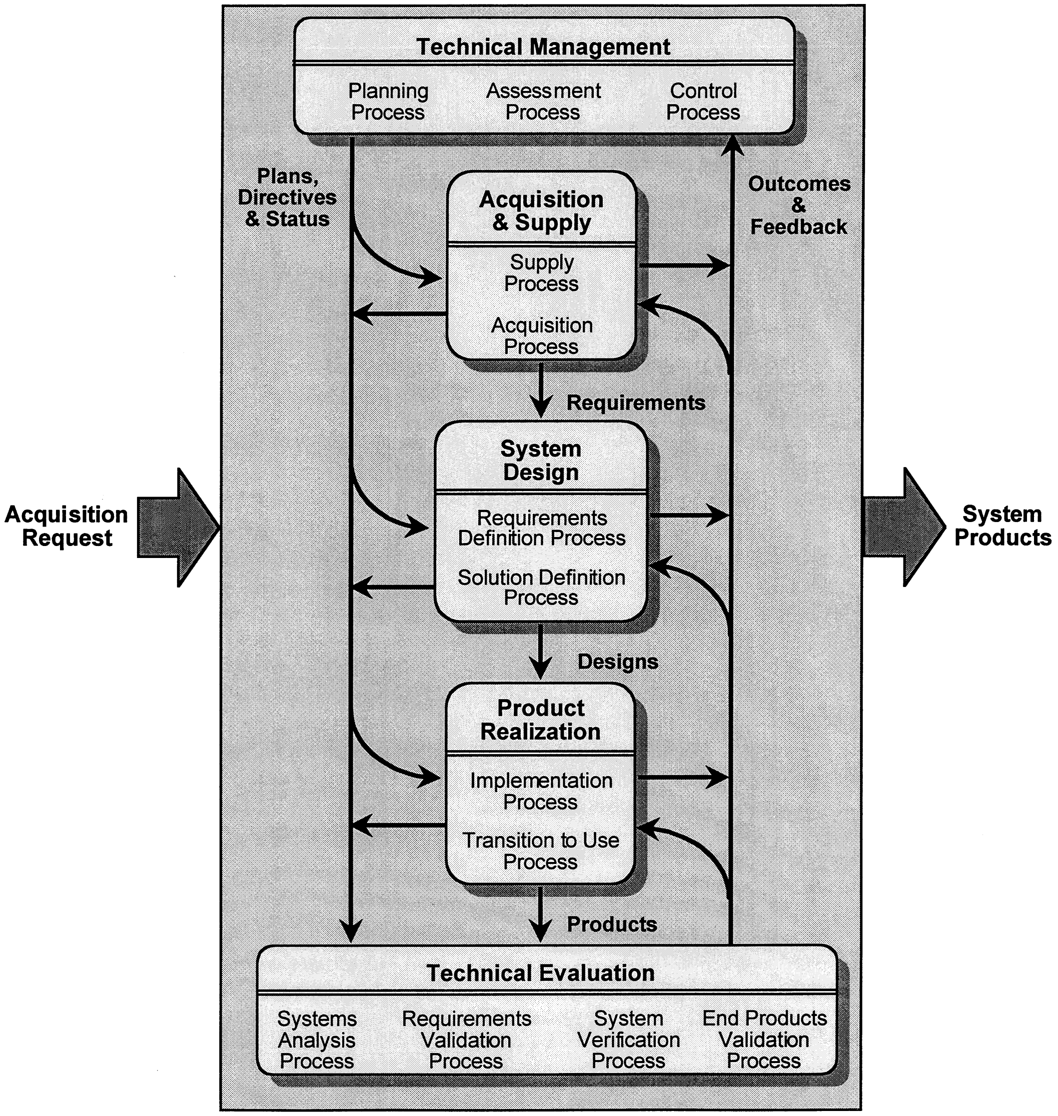


FIGURE 24.3 Top-level view of the processes for engineering a system. (From ANSI/EIA-632-1998. With permission.)

24.5.6 Technical Evaluation Processes

Technical Evaluation provides activities for a project to analyze the effectiveness of its proposed designs, validate the requirements and end products, and to verify that the system and its product meet the specified requirements. The processes necessary to accomplish this are shown in Figure 24.9.

24.6 Project Context

These "technical" processes fit into a larger context of a project (see Figure 24.10), and the project resides in some sort of enterprise, which in turn resides in an environment external to the enterprise. There are processes in the project and within the enterprise (but outside the project) that significantly affect the successful implementation of the technical processes.

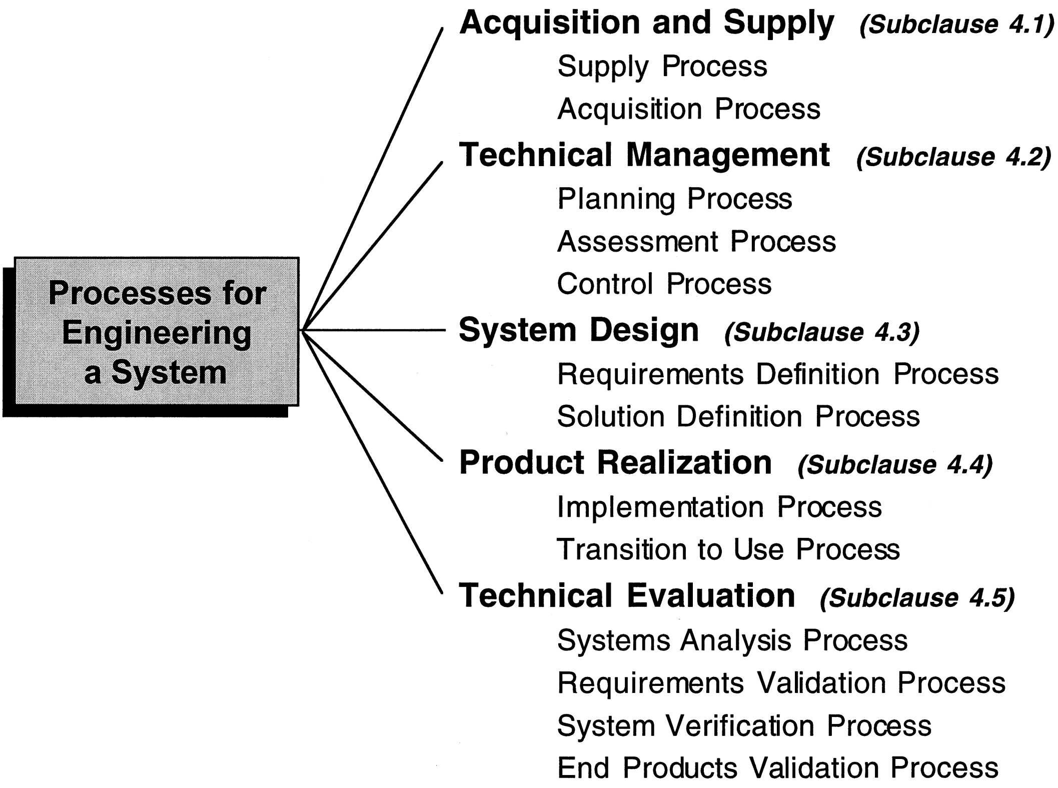

Processes for Engineering a System
Acquisition and Supply (Subclause 4.1)
Supply Process
Acquisition Process
Technical Management (Subclause 4.2)
Planning Process
Assessment Process
Control Process
System Design (Subclause 4.3)
Requirements Definition Process
Solution Definition Process
Product Realization (Subclause 4.4)
Implementation Process
Transition to Use Process
Technical Evaluation (Subclause 4.5)
Systems Analysis Process
Requirements Validation Process
System Verification Process
End Products Validation Process

FIGURE 24.4 Hierarchical view of the processes for engineering a system. (From ANSI/EIA-632-1998. With permission.)

24.7 Key Concepts

To understand the processes as described in this standard, it is essential to understand the distinct use of certain terms and the conceptual models that underlie each process. Some of the key terms are system, product, verification, and validation. Some of the key concepts are building block, end products, associated processes, and development layers.

24.7.1 The System and Its Products

What is a system? The term "system" is commonly used to mean the set of hardware and software components that are developed and delivered to a customer. This standard uses this term in a broader sense in two aspects.

First, the system that needs to be developed consists of not only the "operations product" (that which is delivered to the customer and used by a user), but also the enabling products associated with that operations product. The operations product consists of one or more end products (so-called since these are the elements of the system that "end up" in the hands of the ultimate user). The associated processes are performed using enabling products that "enable" the end products to be put into service, kept in service, and retired from service.

Second, the end products that need to be developed often go beyond merely the hardware and software involved. There are also people, facilities, data, materials, services, and techniques. This is illustrated in Figure 24.12.

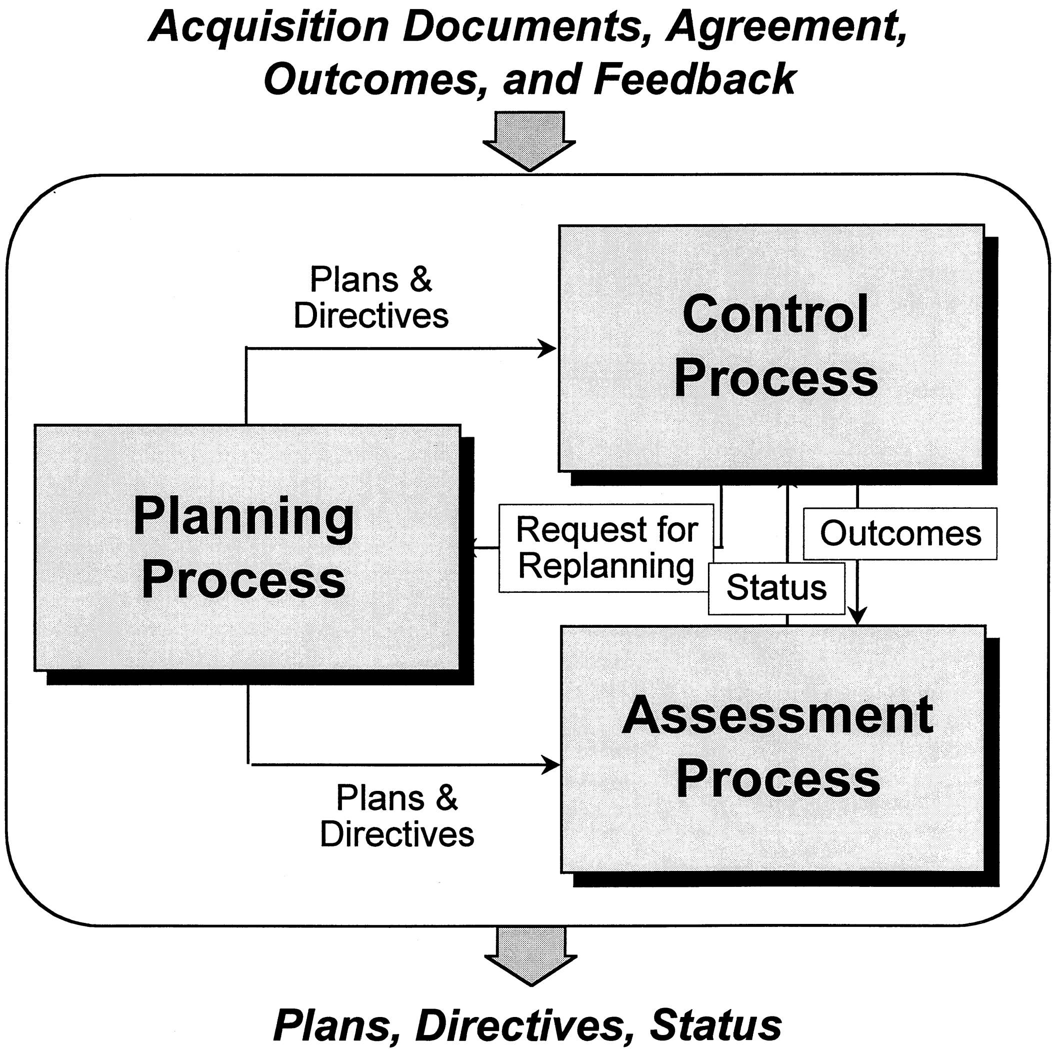


FIGURE 24.5 Technical Management Processes. (From ANSI/EIA-632-1998. With permission.)

This is not intended to be an exhaustive list of the "basic" product types since these will vary depending on the particular business or technology domain. For example, in the television industry, "media" is certainly one of the system elements that constitute the overall system that is developed. "CBS News" might be considered the system, for example, with end products like:

Airwaves, worldwide web (media)
Cameras, monitors (hardware)
Schedule management tools, video compression algorithms (software)
Camera operators, news anchor (personnel)
Studio, broadcasting tower (facilities)
Script, program guide (data)
Pictures, stories (materials)
Airplane transportation, telephone (services)
Presentation method, editing procedures (techniques)

Note that any or all of these end products could be "off-the-shelf." But some of them may need to be conceived, designed, and implemented. Even if one of these items is truly off-the-shelf, it may still need

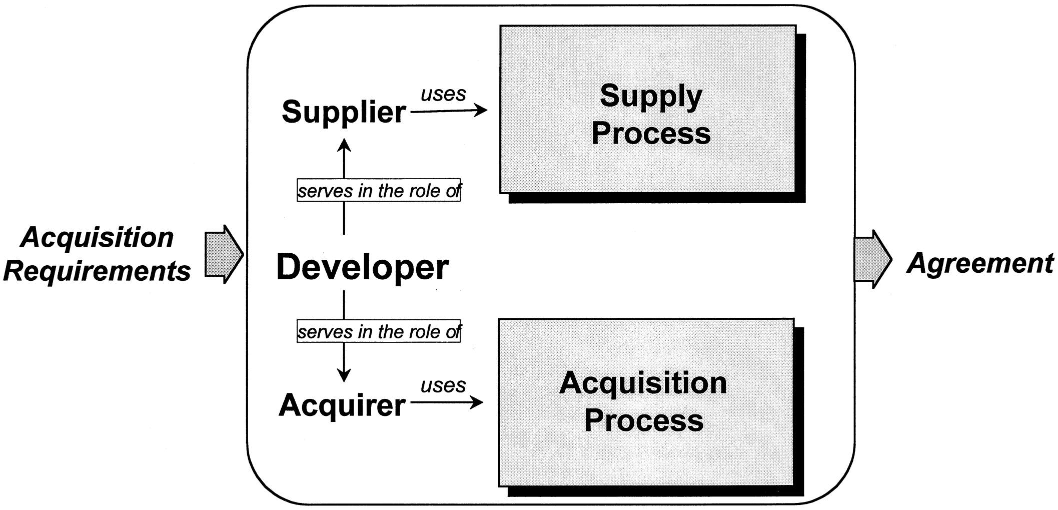


FIGURE 24.6 Acquisition and Supply Processes. (From ANSI/EIA-632-1998. With permission.)

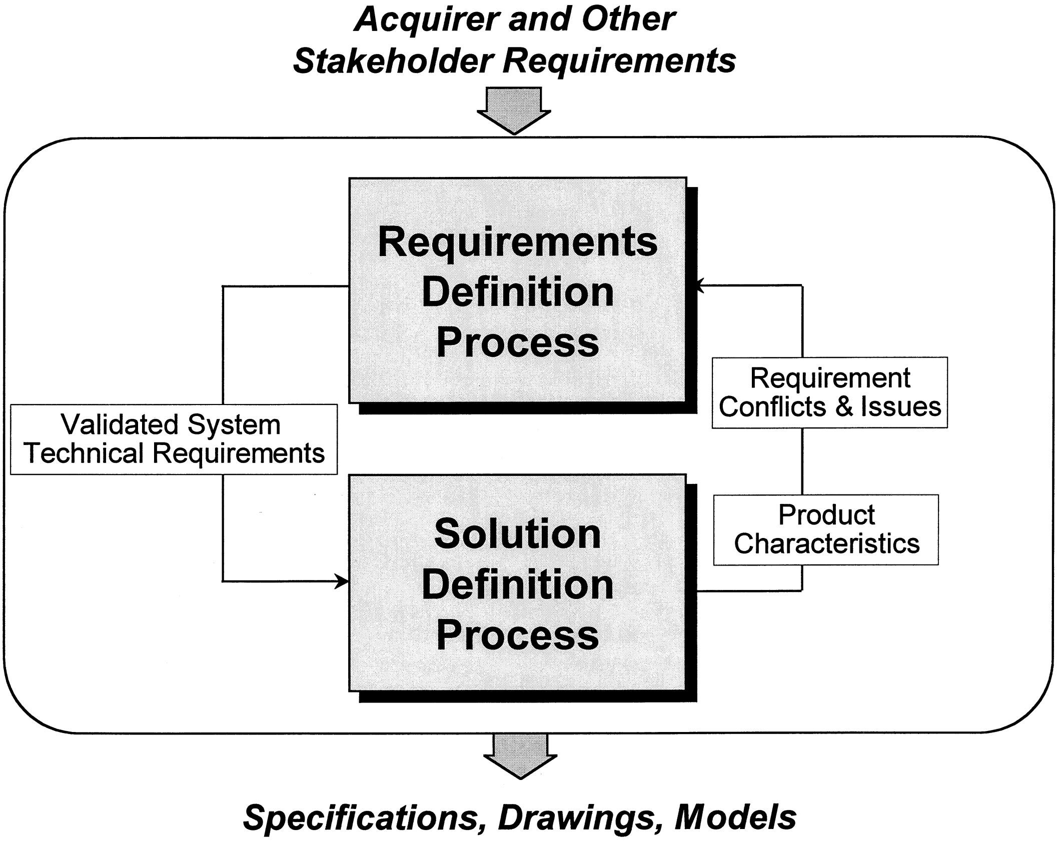

Acquirer and Other Stakeholder Requirements
Requirements Definition Process
Validated System Technical Requirements
Requirement Conflicts & Issues
Product Characteristics
Solution Definition Process
Specifications, Drawings, Models

FIGURE 24.7 System Design Processes. (From ANSI/EIA-632-1998. With permission.)

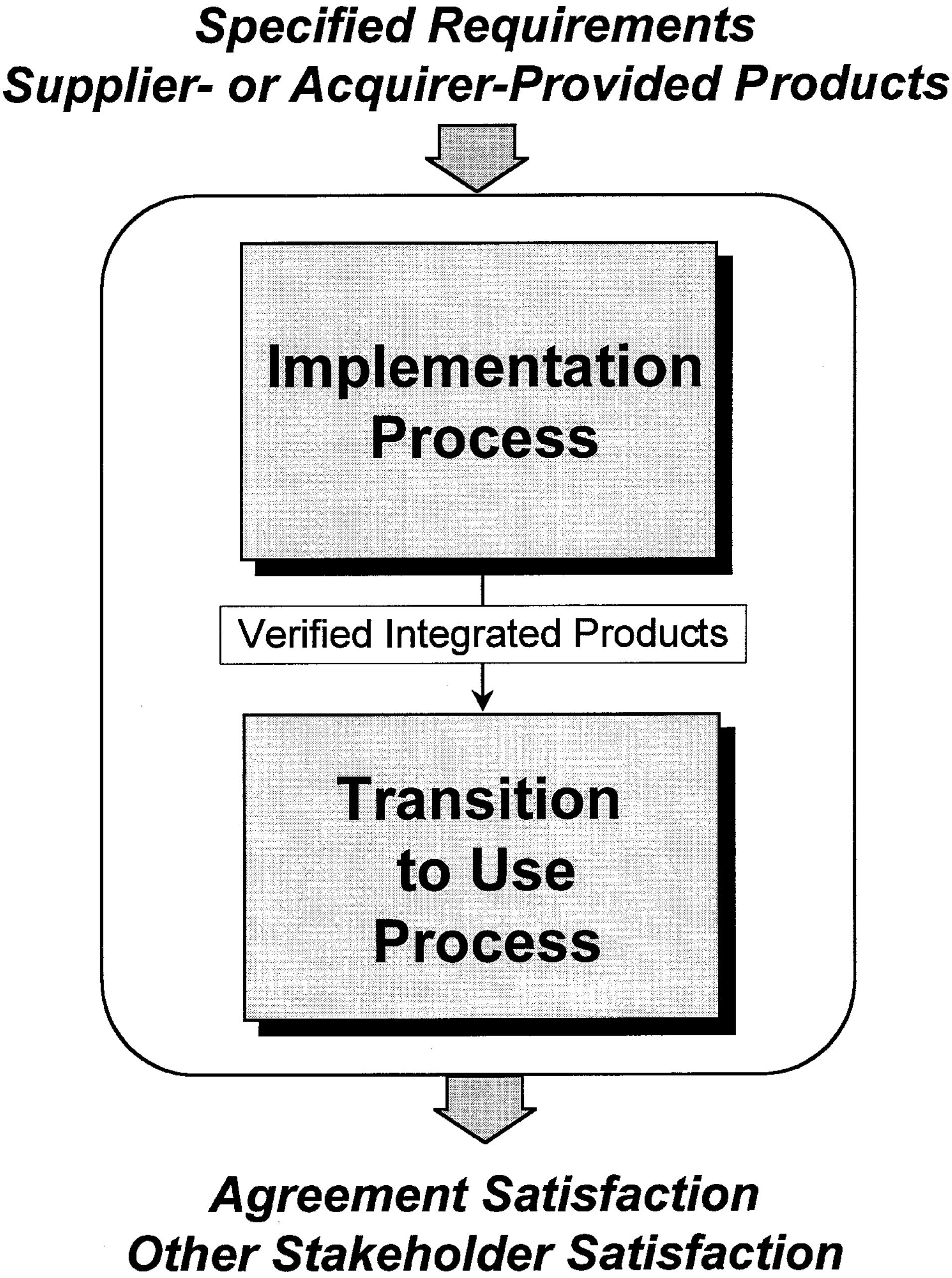

Specified Requirements
Supplier- or Acquirer-Provided Products
Implementation Process
Verified Integrated Products
Transition to Use Process
Agreement Satisfaction
Other Stakeholder Satisfaction

FIGURE 24.8 Product Realization Processes. (From ANSI/EIA-632-1998. With permission.)

some enabling product to allow effective use of that item. For example, even if you can use existing editing procedures, you may need to develop a training program to train the editors.

24.7.2 Building Block Framework

As we can see from the description above of the "CBS News" system, the nonhardware/software items may be crucial to successful realization of the whole system. You may also need to develop the associated processes along with the relevant enabling products. If we tie all these elements together, we can illustrate this using the so-called "building block" shown in Figure 24.13.

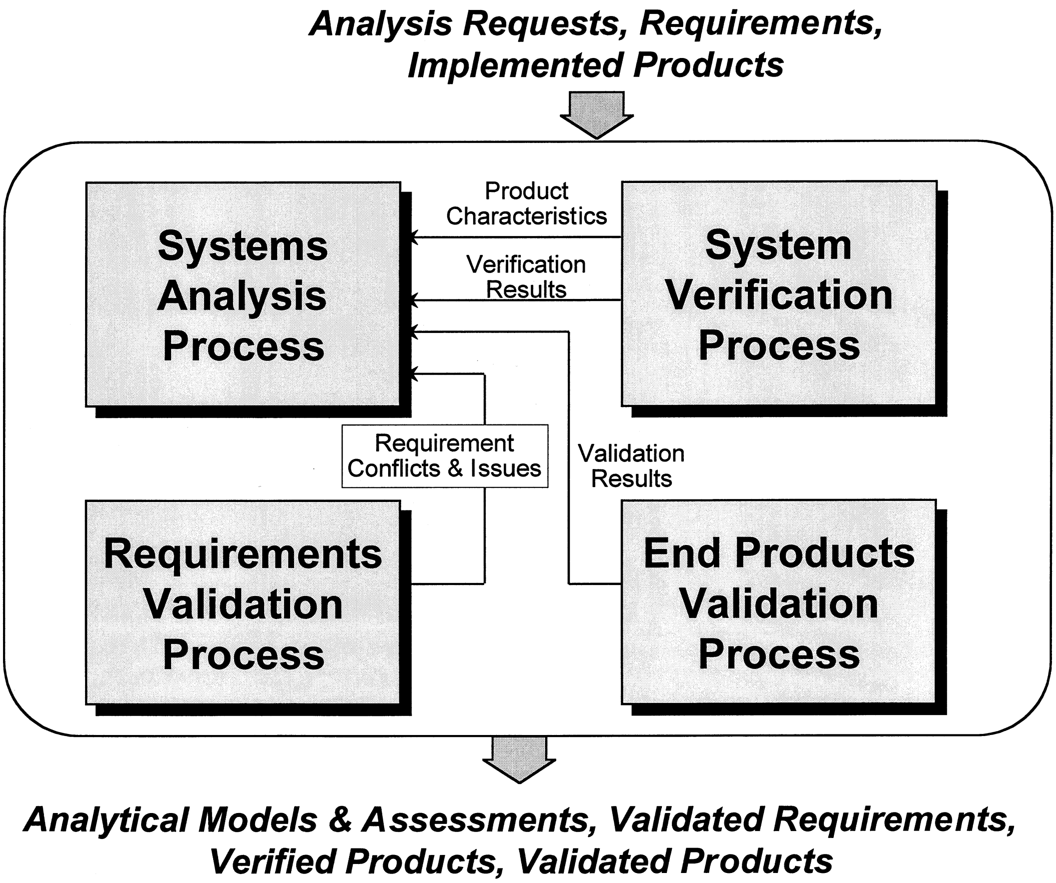

Analysis Requests, Requirements, Implemented Products
Systems Analysis Process
Product Characteristics
Verification Results
System Verification Process
Requirement Conflicts & Issues
Validation Results
Requirements Validation Process
End Products Validation Process
Analytical Models & Assessments, Validated Requirements, Verified Products, Validated Products

FIGURE 24.9 Technical Evaluation Processes. (From ANSI/EIA-632-1998. With permission.)

There are seven associated processes related to these sets of enabling products. These processes are used at various points in the life of a product (sometimes called "system life cycle elements"). Hence, the use of the building block concept is intended to help the developer in ensuring that the full life cycle of the end product is properly considered.

Note that each end product can consist of subsystems. Each of these subsystems may need its own development. The building block can be used at the various "development layers" of the total system. These development layers are illustrated in Figure 24.14.

24.7.3 Development of Enabling Products

As mentioned above, the enabling products may need to be developed also. For each associated process, there could be enabling products that either exist already or that need some degree of development. Figure 24.15 shows how enabling products related to the deployment process have their own building blocks.

24.7.4 Relationship Between the Building Blocks and the Processes

The building blocks relevant to a particular system development can be "stacked" into a System Breakdown Structure (SBS). The System Design Process and Verification and Validation Processes have a special relationship to the SBS, as shown in Figure 24.16.

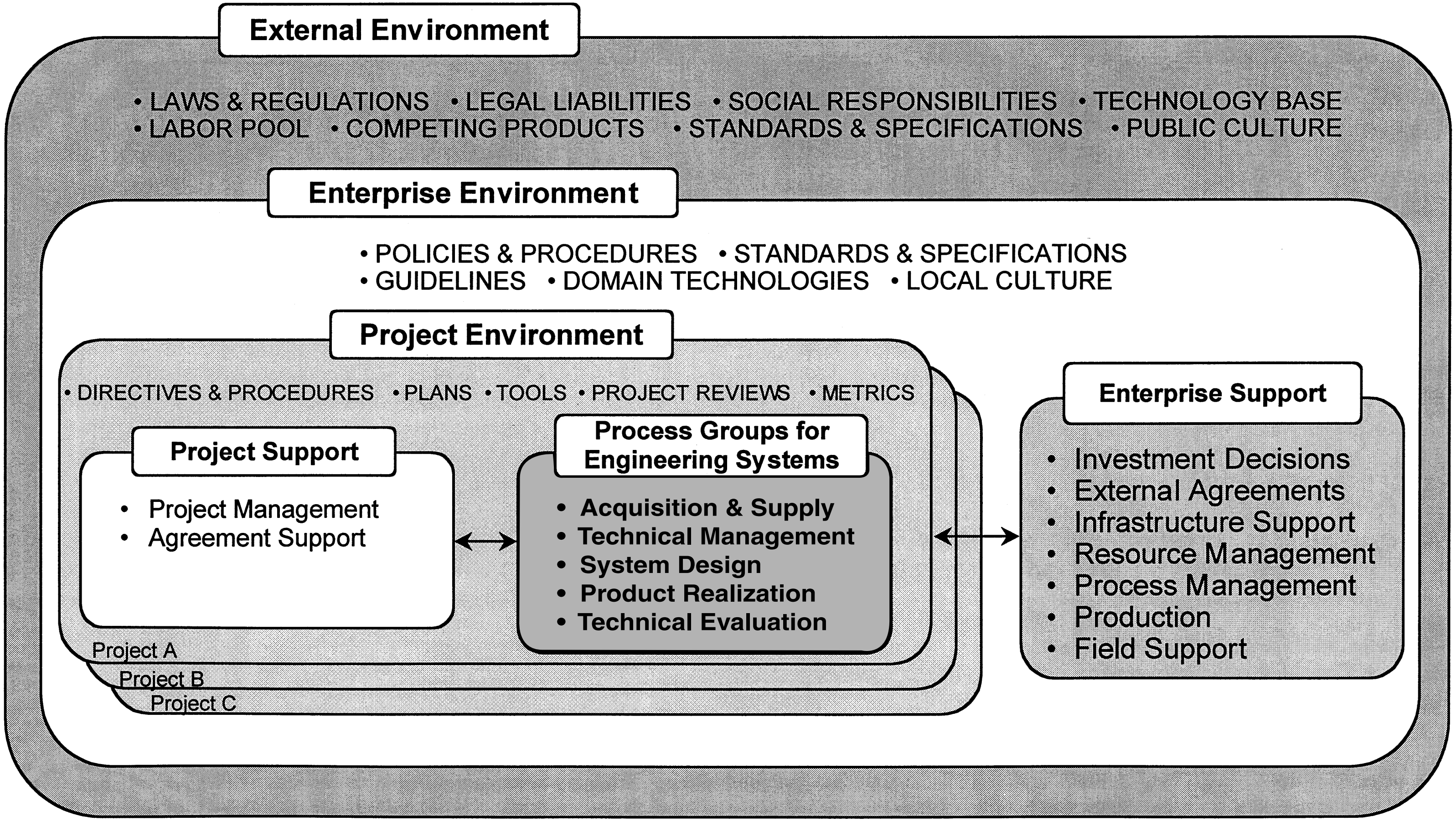


FIGURE 24.10 The technical processes in the context of a project and an enterprise. (From ANSI/EIA-632-1998. With permission.)

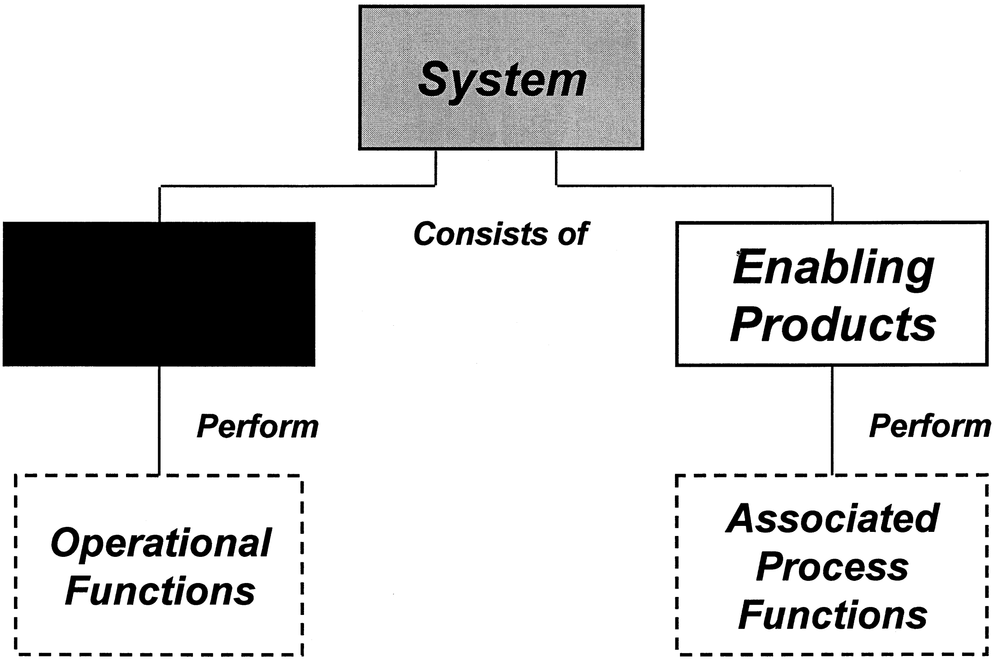


FIGURE 24.11 Constituents of the system. (From ANSI/EIA-632-1998. With permission.)

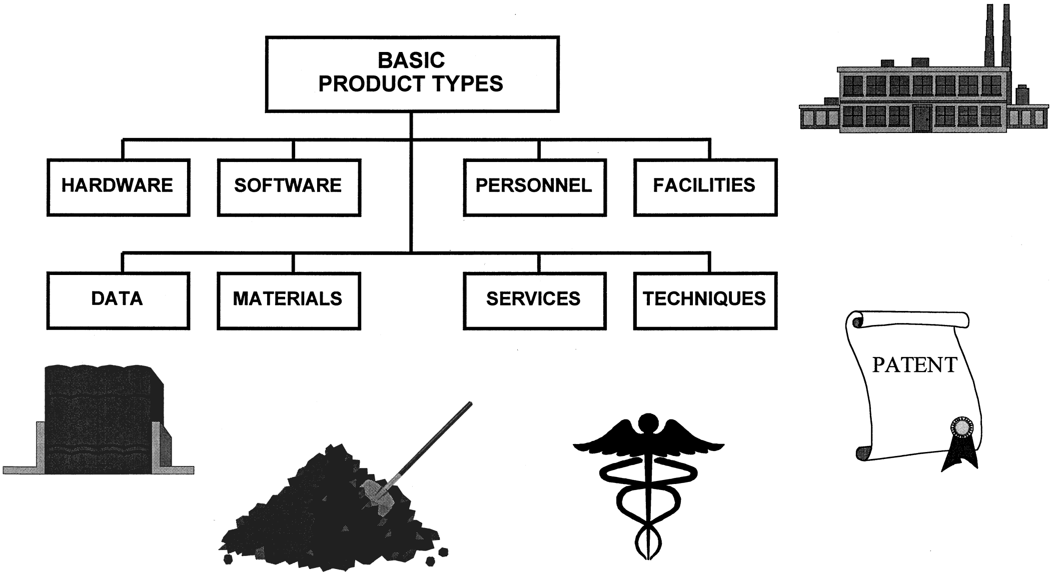


FIGURE 24.12 Different product types that make up a system.

24.7.5 Hierarchy of Building Blocks

Typically, a project is developing a system of such a size that it will require more than one building block to complete the development. Figure 24.17 shows an example of how several building blocks would be related to each other within a project. Notice also how an "adjacent" Project A has building blocks that might have interfaces to the systems under development by Project B. There also may be building blocks above and below a project.

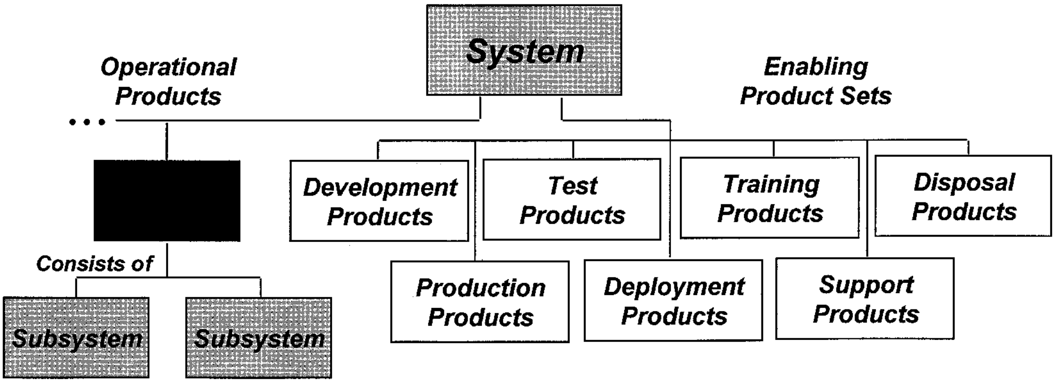


FIGURE 24.13 The building block concept. (From ANSI/EIA-632-1998. With permission.)

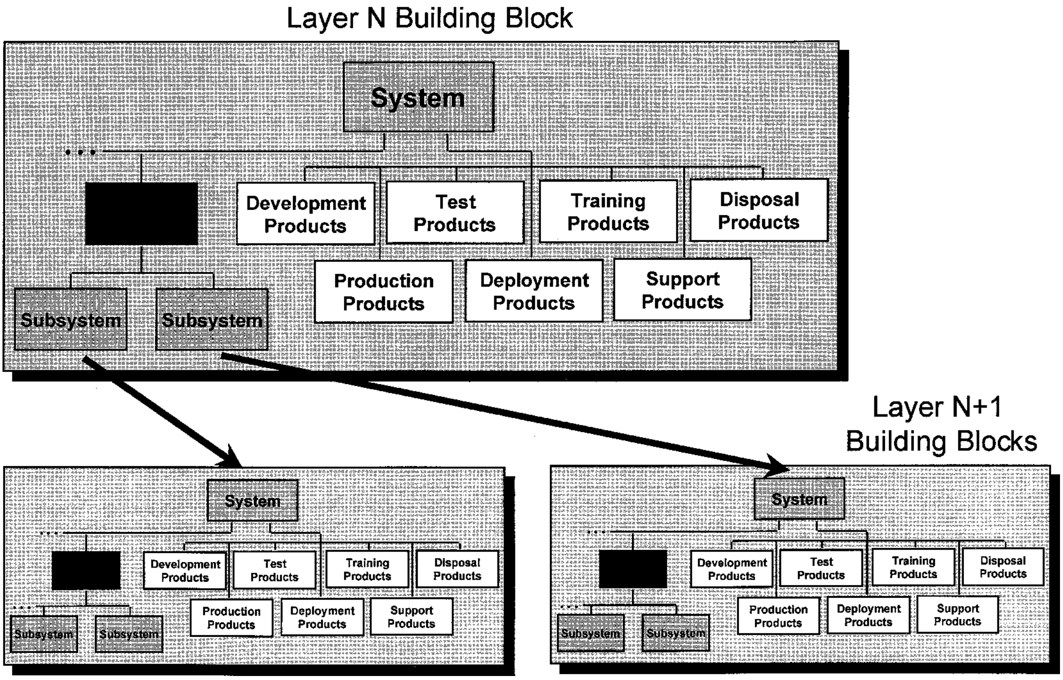
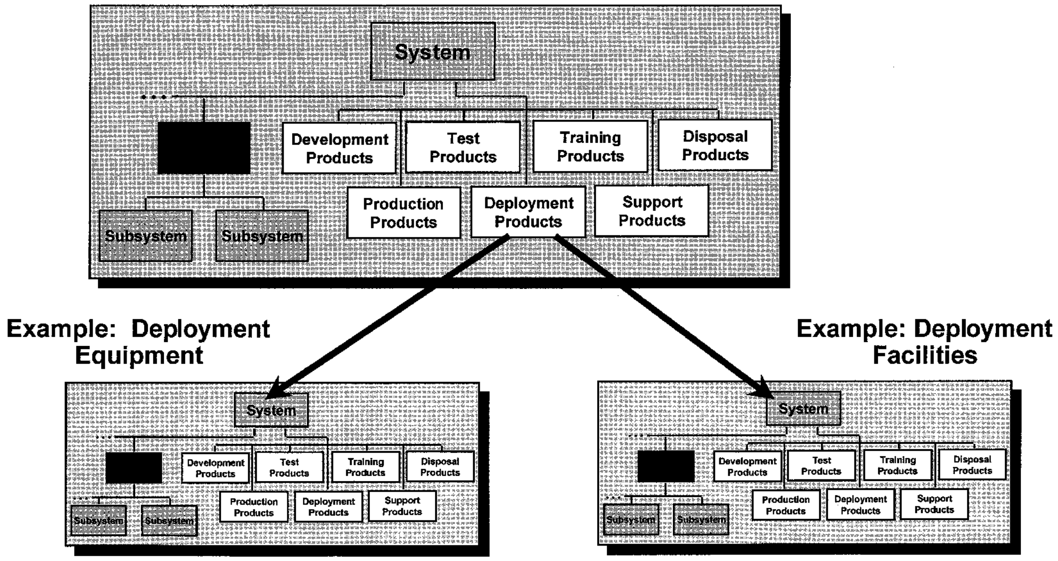


FIGURE 24.14 Development layers concept. (From ANSI/EIA-632-1998. With permission.)

24.7.6 Requirements

Requirements are especially useful for engineering a system, especially when the system consists of several building blocks. Requirements act as a kind of “decoupling mechanism” between the building blocks. They are the “terms and conditions” between the layers of development. Requirements start out as vague, usually nontechnical stakeholder requirements and evolve into more technically precise and verifiable technical requirements. This is illustrated in Figure 24.18.

Lower-level requirements must be derived from higher-level requirements. This is usually accomplished through logical and physical analyses and design activities to determine the requirements that apply to the design solution. This is illustrated in Figure 24.19 which shows the different types of requirements dealt with by the processes described in EIA 632.



Other Deployment Enabling Products Possibly Needing Development:

- v Deployment Procedures (e.g. installation manual)
- v Deployment Personnel (e.g. field technicians, installers)
- v Deployment Services (e.g. shipping & receiving, transportation)

FIGURE 24.15 Development of enabling products. (Adapted from ANSI/EIA-632-1998. With permission.)

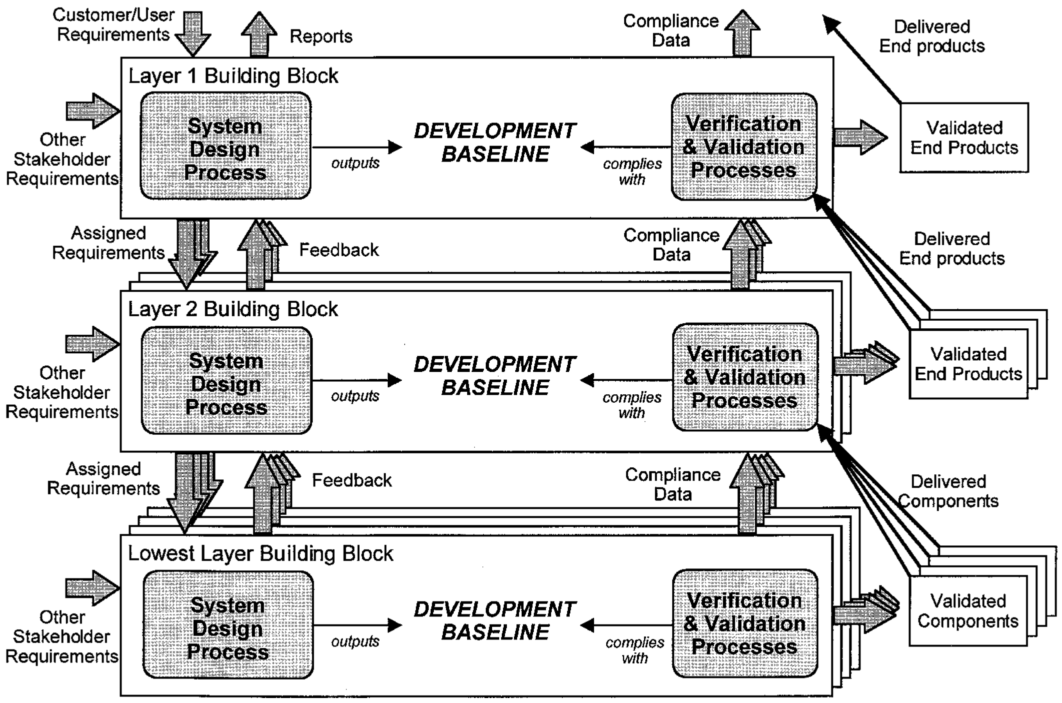


FIGURE 24.16 Development layers in a project context. (Adapted from ANSI/EIA-632-1998. With permission.)

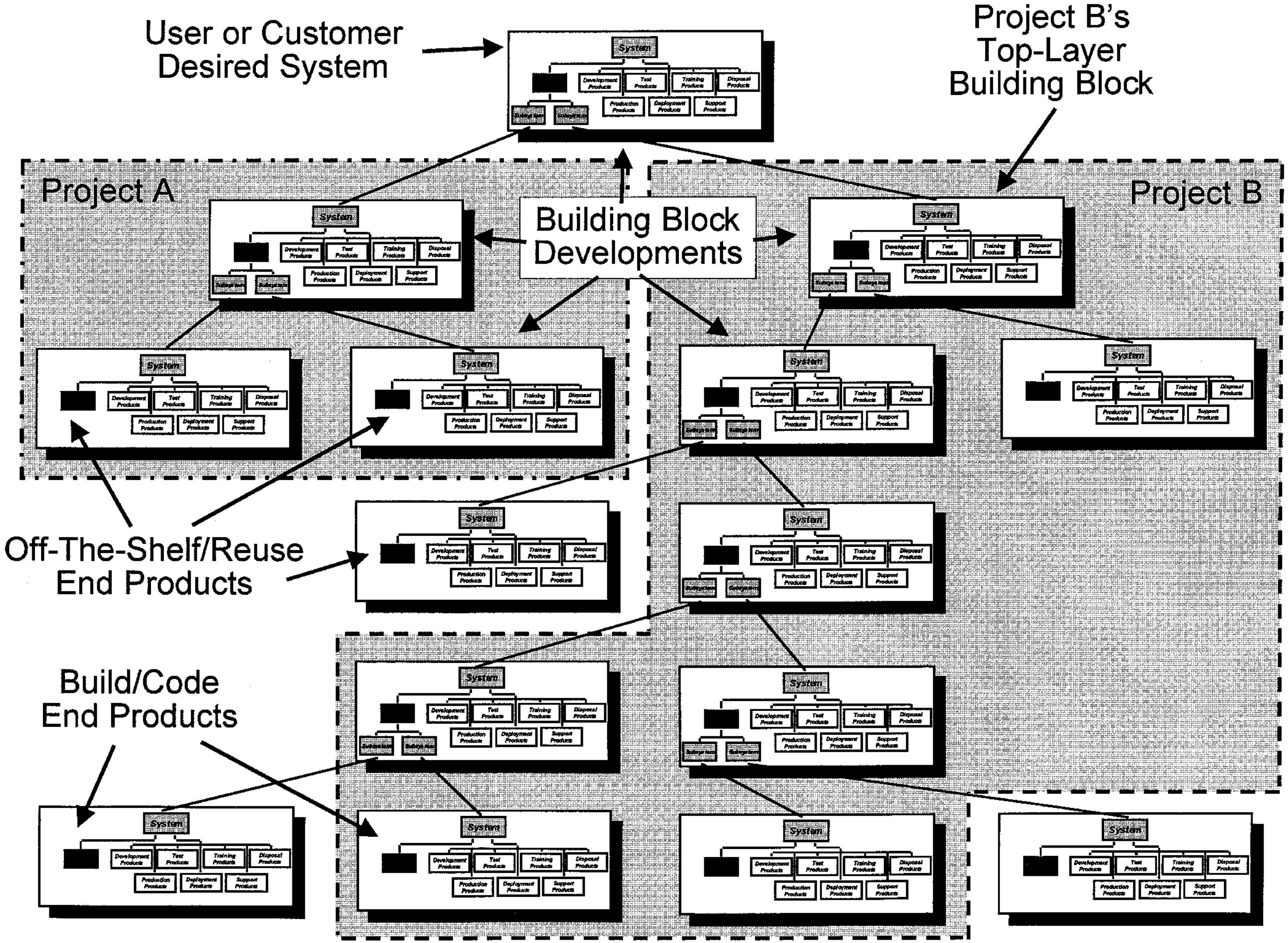


FIGURE 24.17 Building blocks in the context of a several projects. (From ANSI/EIA-632-1998. With permission.)

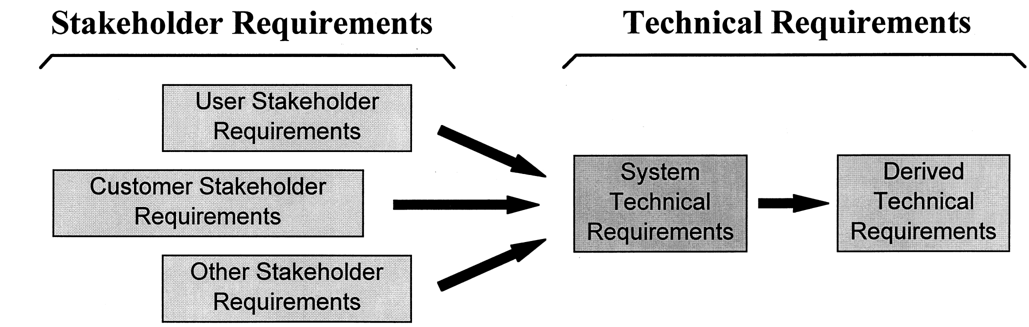

Stakeholder Requirements
Technical Requirements
User Stakeholder Requirements
Customer Stakeholder Requirements
Other Stakeholder Requirements
System Technical Requirements
Derived Technical Requirements

FIGURE 24.18 Evolution of requirements. (*Source*: ANSI/EIA-632-1998. With permission.)

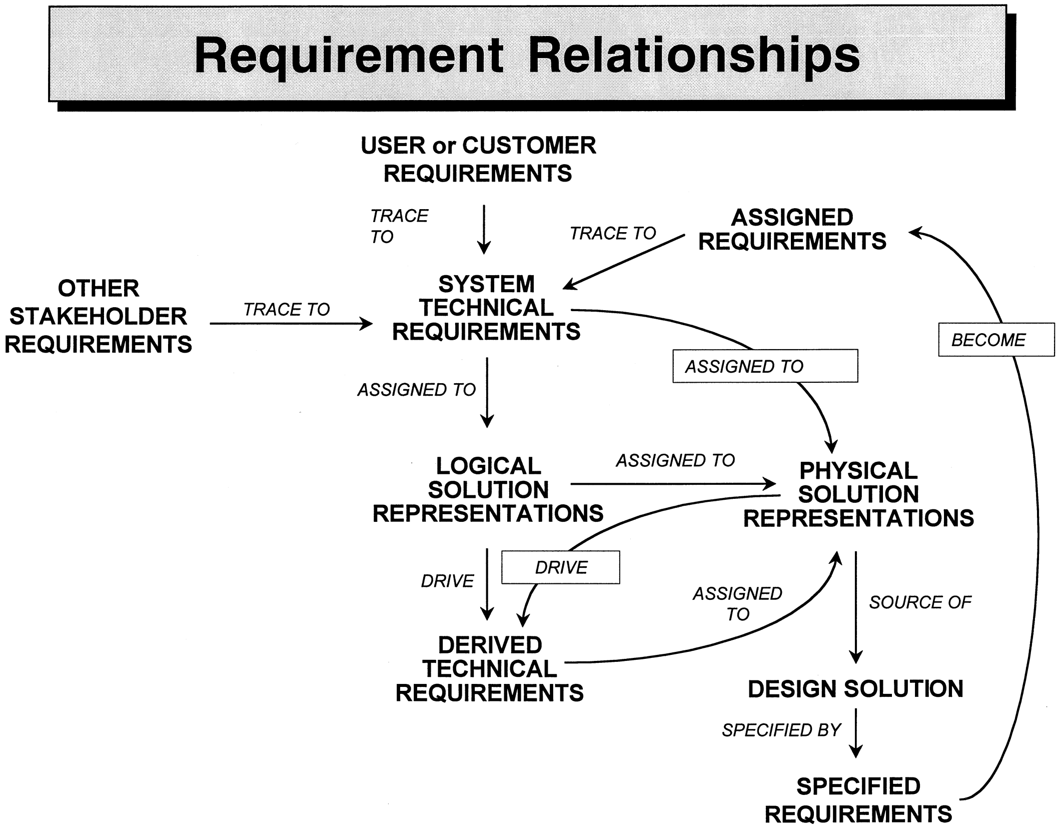

Requirement Relationships
USER or CUSTOMER REQUIREMENTS
TRACE TO
TRACE TO
ASSIGNED REQUIREMENTS
OTHER STAKEHOLDER REQUIREMENTS
TRACE TO
SYSTEM TECHNICAL REQUIREMENTS
BECOME
ASSIGNED TO
ASSIGNED TO
LOGICAL SOLUTION REPRESENTATIONS
ASSIGNED TO
PHYSICAL SOLUTION REPRESENTATIONS
DRIVE
DRIVE
ASSIGNED TO
SOURCE OF
DERIVED TECHNICAL REQUIREMENTS
DESIGN SOLUTION
SPECIFIED BY
SPECIFIED REQUIREMENTS

FIGURE 24.19 Types of requirements and their interrelationships. (From ANSI/EIA-632-1998. With permission.)

Requirements generally do not come from a particular customer. And even when they do, as is often the case in government-sponsored developments, they do not represent the full spectrum of the requirements that will eventually need to be defined for development of the products of a system.

User Requirements. User requirements are often nontechnical in nature and usually conflict with each other. These need to be translated into "technical requirements" that are in the vernacular of the engineers on a project and are specific to the domain of the technology to be used in the system.

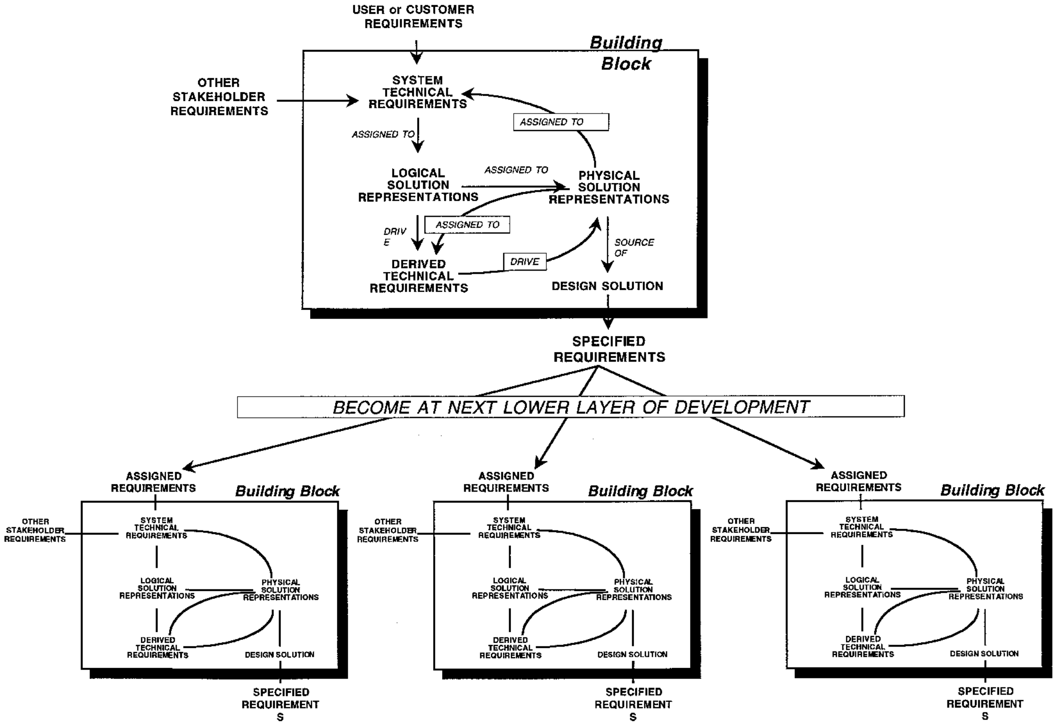

USER or CUSTOMER REQUIREMENTS
Building Block
OTHER STAKEHOLDER REQUIREMENTS
SYSTEM TECHNICAL REQUIREMENTS
ASSIGNED TO
ASSIGNED TO
LOGICAL SOLUTION REPRESENTATIONS
ASSIGNED TO
PHYSICAL SOLUTION REPRESENTATIONS
DRIVE
ASSIGNED TO
SOURCE OF
DERIVED TECHNICAL REQUIREMENTS
DRIVE
DESIGN SOLUTION
SPECIFIED REQUIREMENTS
BECOME AT NEXT LOWER LAYER OF DEVELOPMENT
ASSIGNED REQUIREMENTS
Building Block
OTHER STAKEHOLDER REQUIREMENTS
SYSTEM TECHNICAL REQUIREMENTS
LOGICAL SOLUTION REPRESENTATIONS
PHYSICAL SOLUTION REPRESENTATIONS
DERIVED TECHNICAL REQUIREMENTS
DESIGN SOLUTION
SPECIFIED REQUIREMENTS

FIGURE 24.20 Layers of requirements as they relate to the layers of development. (Adapted from ANSI/EIA-632-1998. With permission.)

Customer Requirements. Customers will often translate their perceived user requirements into a set of requirements to be given to a development project. These also, like the user requirements, are often not technical enough and usually conflict with each other. Moreover, a particular project may have more than one customer for its products.

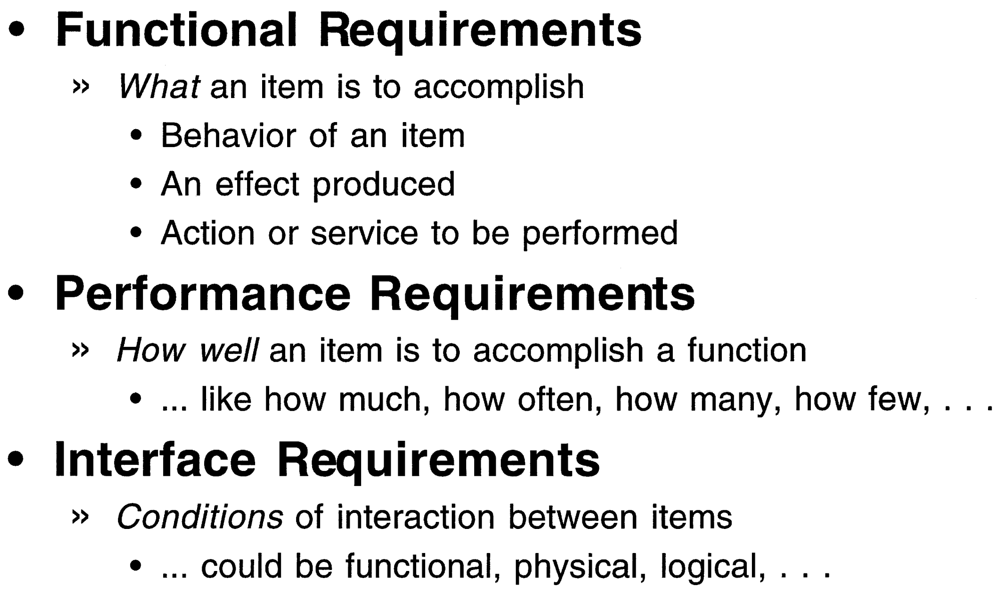
Stakeholder Requirements. In defining the technical requirements for the system, one must consider that there are other stakeholders for that system. For example, the manufacturing organization within your company may desire that you use their existing processes, tools, facilities, etc. There are constraints associated with these "enabling products." Hence, you must identify the stakeholder requirements that drive the development.

Requirements Decomposition. Once the system technical requirements are defined, further requirements are often "derived" by analyzing both the logical and physical aspects of the system. Some of these derived requirements, plus whatever system technical requirements are relevant, are "specified" for the system, its end products, and possibly subsystems of those end products.

Given these specified requirements for an item, the process starts all over again for items needing further development. In other words, another layer of building blocks may be required to develop an item far enough along such that the bottommost item can be procured from a supplier. This is illustrated in Figure 24.20.

24.7.7 Functional, Performance, and Interface Requirements

Another way to look at requirements is to categorize them as functional (what the product must accomplish), performance (how well the product must accomplish each function), and interface (under what conditions must the functions be accomplished). This is illustrated in Figure 24.21.



- **Functional Requirements**
  - » *What* an item is to accomplish
    - Behavior of an item
    - An effect produced
    - Action or service to be performed
- **Performance Requirements**
  - » *How well* an item is to accomplish a function
    - ... like how much, how often, how many, how few, . . .
- **Interface Requirements**
  - » *Conditions* of interaction between items
    - ... could be functional, physical, logical, . . .

FIGURE 24.21 Types of requirements.

24.7.8 Verification and Validation

Verification and validation are both very important in engineering a system. Verification is the act of determining if a product meets its specified requirements. Validation is the act of determining if a product satisfies its stakeholders. This is illustrated in Figure 24.22

Defining Terms

The following definitions are extracted from the standard.

Building block: A representation of the conceptual framework of a system that is used for organizing the requirements, work, and other information associated with the engineering of a system. An element in the structured decomposition of the system.

Enabling product: Item that provides the means for (a) getting an end product into service, (b) keeping it in service, or (c) ending its service.

End product: The portion of a system that performs the operational functions and is delivered to an acquirer.

Process: A set of interrelated tasks that, together, transform inputs into outputs.

Product: (1) An item that consists of one or more of the following: hardware, software, firmware, facilities, data, materials, personnel, services, techniques, and processes; (2) a constituent part of a system.

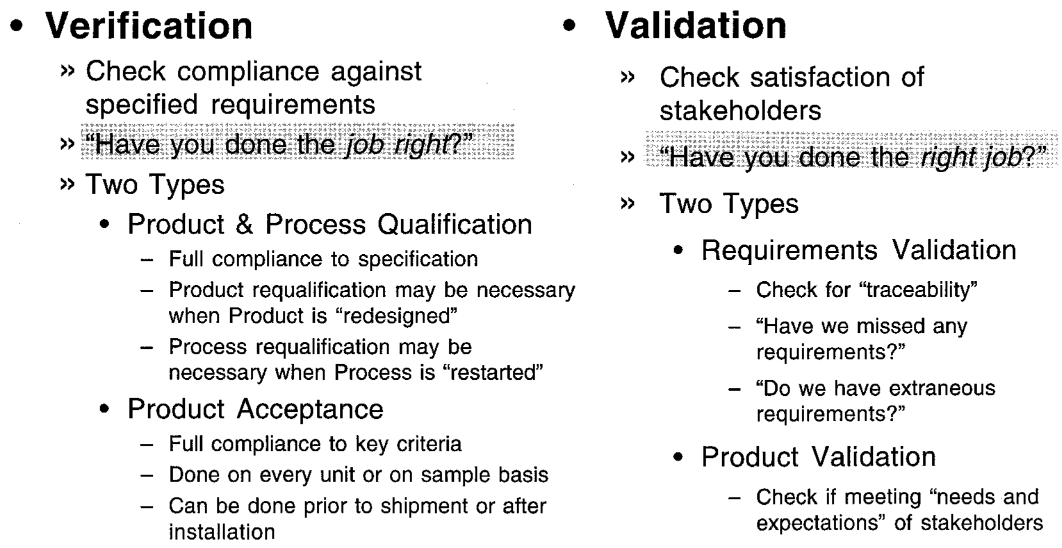
Requirement: Something that governs what, how well, and under what conditions a product will achieve a given purpose.

Stakeholder: An enterprise, organization, or individual having an interest or a stake in the outcome of the engineering of a system.

Subsystem: A grouping of items that perform a set of functions within a particular end product.

System: An aggregation of end products and enabling products to achieve a given purpose.

Validation: (1) Confirmation by examination and provision of objective evidence that the specific intended use of an end product (developed or purchased), or an aggregation of end products, is



- **Verification**
  - » Check compliance against specified requirements
  - » "Have you done the *job right*?"
  - » Two Types
    - Product & Process Qualification
      - Full compliance to specification
      - Product requalification may be necessary when Product is "redesigned"
      - Process requalification may be necessary when Process is "restarted"
    - Product Acceptance
      - Full compliance to key criteria
      - Done on every unit or on sample basis
      - Can be done prior to shipment or after installation
- **Validation**
  - » Check satisfaction of stakeholders
  - » "Have you done the *right job*?"
  - » Two Types
    - Requirements Validation
      - Check for "traceability"
      - "Have we missed any requirements?"
      - "Do we have extraneous requirements?"
    - Product Validation
      - Check if meeting "needs and expectations" of stakeholders

FIGURE 24.22 Distinction between verification and validation.

accomplished in an intended usage environment; (2) confirmation by examination that requirements (individually and as a set) are well formulated and ar usable for intended use.

Verification: Confirmation by examination and provision of objective evidence that the specified requirements to which an end product is built, coded, or assembled have been fulfilled.

References

ANSI/EIA 632, *Processes for Engineering a System*. 1998.

EIA/IS 632, *Systems Engineering*. 1994.

Martin, J. N., "Evolution of EIA 632 from an Interim Standard to a Full Standard." Proc. INCOSE 1998 Int. Symp., 1998.

Further Information

The purpose of this chapter is to give a high-level overview of the processes for engineering a system described in ANSI/EIA 632. Further details can be found in the full publication of the standard or by contacting the EIA directly at 2500 Wilson Boulevard, Arlington, Virginia or at their Website (www.eia.org).