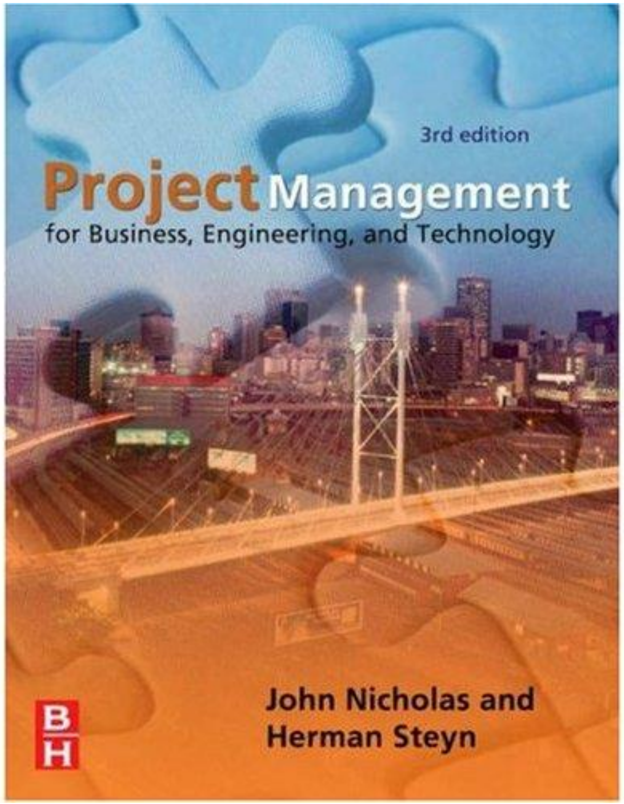
Appendix to Chapter 2
Stages of Systems Engineering

Project Management for Business, Engineering, and Technology



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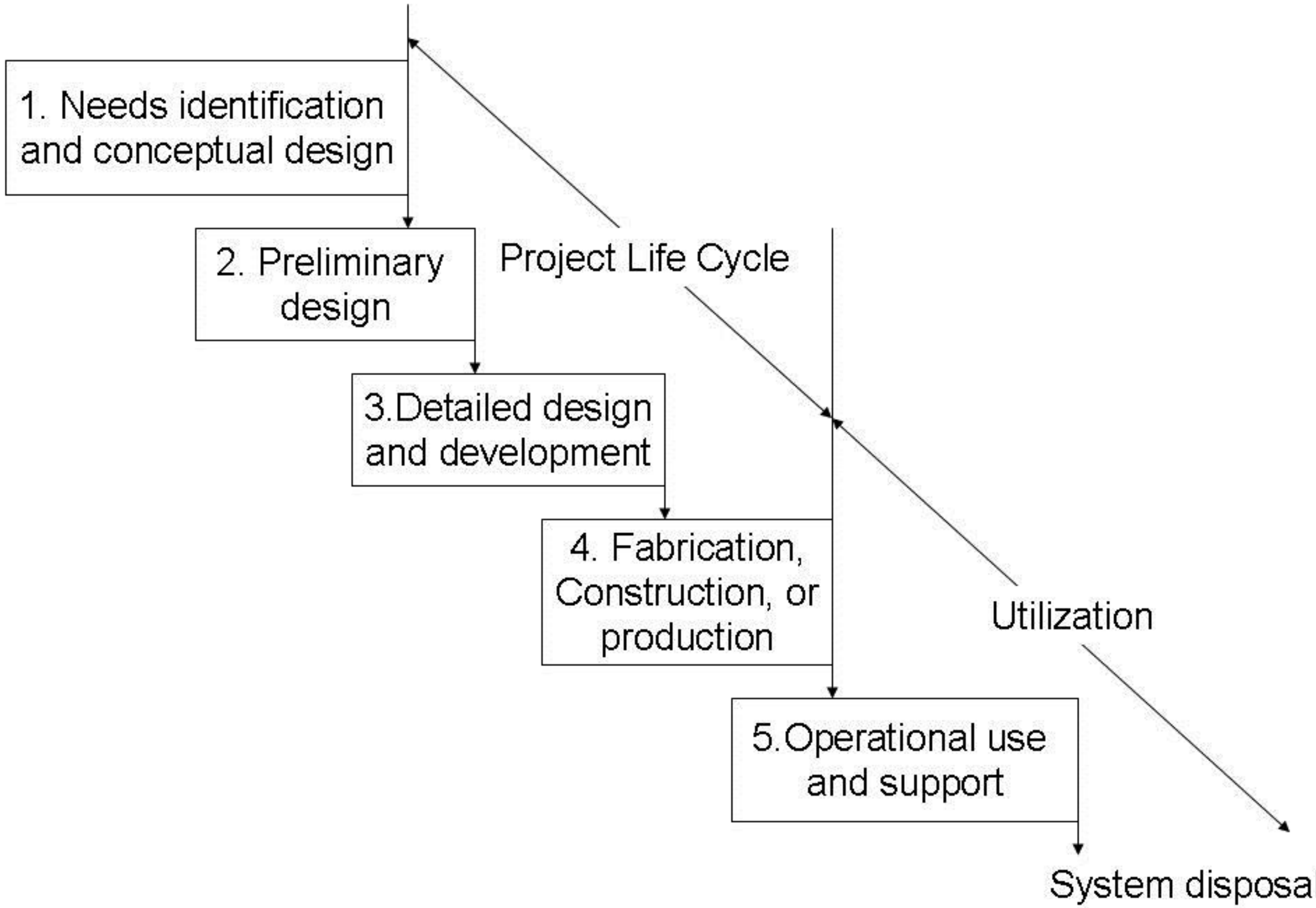
Stages of the Systems Engineering Process



Stage 1 of the Systems Engineering Process: Needs Identification and Conceptual Design

Main tasks of this stage

- Define stakeholder needs and requirements
- Feasibility analysis
- High-level requirements analysis
- System-level synthesis
- Create system specification

Stage 1: Needs Identification and Conceptual Design

- Identify the stakeholders, including the client or customer and others who will be affected by or able to impact (contribute to, support, or block) the system.
- Develop a clear conception of the need or problem begins by asking basic questions:

1. How did the problem or need arise?

2. Who believes it to be a problem or feels the need?

3. Is this the root problem or need, or is it a manifestation of some other, deeper problem?

4. Why is a solution important? How much money (or time, etc.) will it save? What is the value of the system?

5. How important is the need? Would resources be better applied to another need?

Stage 1: Needs Identification and Conceptual Design

Requirements Definition

High-level requirements incorporate everything important about the system, including

- **Objectives.** The overarching aim of the system in terms of several objectives, each elaborated in terms of a set of requirements.
- **Life cycle.** How the system will be built, tested, distributed, marketed, financed, operated, maintained, and disposed of (includes ancillary issues, “side items,” and environmental impacts.
- **Operational modes.** The multiple environments and different ways in which the system will be used. Each constitutes a different set of requirements.
- **Constraints.** Policies, procedures, and standards; available materials, knowledge, and technology; and limited time, funding, and resources.
- **Interfaces.** An interface occurs wherever a system receives input from or provides output to other systems. Requirements specify the interfaces and mandated or pre-specified inputs or outputs at each.
- Requirements stated in the language of the stakeholders are compiled in the ***stakeholder requirements document*** (SRD).

Stage 1: Needs Identification and Conceptual Design

Requirements Definition

Feasibility

- Given high-level requirements,next step is to identify alternative high-level (system-level) solutions.
- These are evaluated in terms of costs, risks, effectiveness, and benefits using studies and models.

System Requirements Analysis

- Next step: specify what *the* system *must do* to be able to meet the requirements in the SRD; this is purpose of ***system requirements.***
- System requirements tell the designers the *functions* the system must perform and the physical characteristics it must possess to meet requirements in the SRD.

Stage 1: Needs Identification and Conceptual Design

Requirements Definition

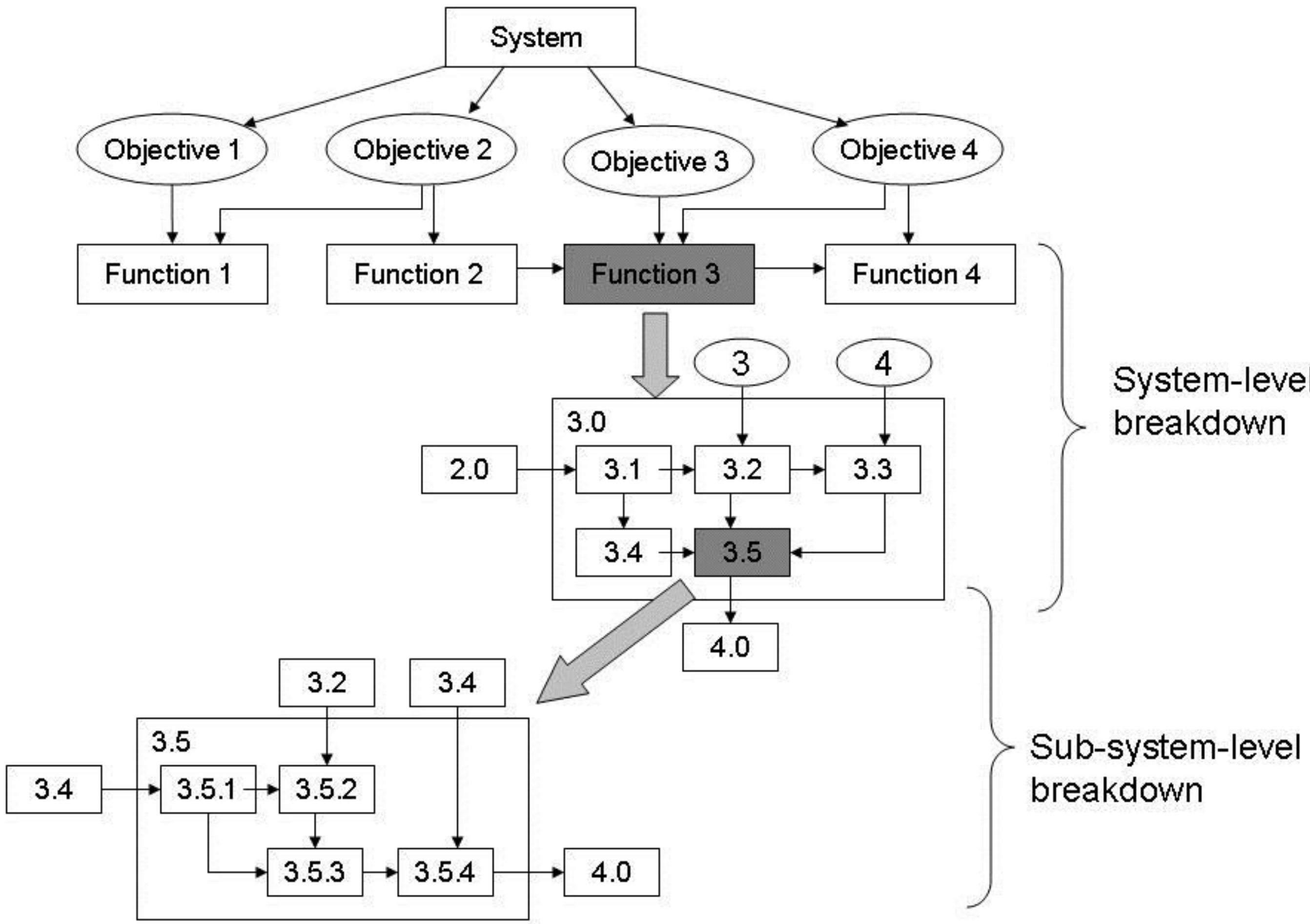
System requirements analysis addresses three kinds of requirements: functional, performance, verification.

Functional Requirements

- These specify the functions the system must perform to meet requirements in the SRD, including those for support, operation and maintenance.
- A tool for analyzing and defining functional requirements is the *functional flow block diagram, FFBD*. Each block represents a function that the system must perform to satisfy objectives or requirements.

Functional flow block diagram, FFBD

Each block represents a function; each function is defined in greater detail by decomposing it into sub-functions



Stage 1: Needs Identification and Conceptual Design

Requirements Definition

Performance Requirements

- Associated with each functional requirement are performance requirements
- Functional requirement state *what* the system must do; performance requirements specify *how well* it must do it
- Are usually specified in physical parameters, e.g., speed, acceleration, weight, tolerance, power, force, time.

Verification Requirements

- Accompanying each performance requirement is a set of verification requirements
- These specify the procedures, measures, and tests to verify that the performance requirement has been met

Stage 1: Needs Identification and Conceptual Design

Synthesis

Synthesis looks at relationships among the system-level requirements and alternative ways to satisfy them; e.g.

- Create newly designed or technologies and parts
- Procure existing—"off the shelf" (OTS)—designs and products
  - OTS items can be readily purchased or built; they are often preferable to newly designed ones because they are readily available and sometimes less costly
- When no OTS item is available and creating a new design would be too costly, risky, or time-consuming, the requirements must be revised.

Stage 1: Needs Identification and Conceptual Design

Synthesis

Result of synthesis is the "***system specification***."

The system specification

- Is a comprehensive list of all the functions the new system must satisfy
- Identifies a firm or tentative solution (whether the item will be developed or bought) for each function.
- Serves as a guide for designers in the stages of preliminary and detailed system design.

Stage 2 of the Systems Engineering Process: Preliminary Design

Main tasks of Preliminary Design stage

- Translate system-level functional requirements into design requirements for the subsystems.
- Perform tradeoff studies of high-level elements comprising the system
- Allocate the system-level requirements among the subsystems.

Stage 2: Preliminary Design

Identify Functions of Subsystems

- Repeat the FFBD process to decompose the system-level functions into subsystem-level functions
- As before, define functional, performance, and verification requirements for each function.
- The degree of detail of the FFDBs is whatever necessary to define each subsystem and permit decisions about whether each function can be met with an OTS design or product or must be designed and built from scratch.

Stage 2: Preliminary Design

Grouping of Functions

System architecture

- Next step is to group the identified functions and requirements according to the desired *physical architecture* of the system (i.e., how the major components in the system are configured or arranged to satisfy the functions of the system.
- Example, architecture for a bicycle:
  - *Major components:* two wheels, frame, seat, pedals and chain, handle bar.
  - *Configuration:* wheel attached at each end of frame; front wheel pivots on frame; seat mounted on frame; pedals attached to frame but linked by chain to rear wheel.

Stage 2: Preliminary Design

Grouping of Functions

Configuration Items

- Each subsystem that will perform a major function is called a ***configuration item*** or CI.
- From here on, the history of each CI will be documented and monitored throughout the system's complete life cycle—its design, production, and operation.
- Documenting and tracking the CI's is called *configuration management.*
  - The purpose is to ensure that any changes in the design, production, or usage of the CI do not alter or degrade its ability to meet the functional requirements.

Stage 2: Preliminary Design

Requirements Allocation

- As of this point, the design consists of
  - (1) a list of the functional requirements
  - (2) a high-level design of the system—the major subsystem or CI's, and the system architecture
- Next step is to "allocate" the functional requirements to the CIs, i.e., *assign* responsibility for each functional requirement to one or more of the CI's.
- Purpose is to ensure that every functional requirement will be addressed by at least one subsystem or CI.
- Resulting allocations are shown in an "allocation" or "traceability" matrix

Allocation (or Traceability) Matrix

Requirements \ CI's	Fuselage	Motor	Avionics	Cabin	Wing	S/F Control	Landing Gear
Functional							
Thrust of motor 1.1		◆					
Motor burn time 1.2		◆					
Flight trajectory 1.3		◆			◆		
Cabin atmosphere 3.1	◆			◆			
Acceleration force 3.2		◆					
Fuel and fuel handling economy 4.1		◆					
Structural materials economy 4.2	◆				◆		
OTS technology and systems 4.3	◆		◆			◆	◆
Refueling 5.3		◆					
Cabin cleaning 5.4				◆			
Structural integrity 6.1	◆				◆		
Access/egress 6.2	◆			◆			
Safety equipment 6.3				◆			
Ease of handling 6.5	◆	◆			◆	◆	
Physical							
Cabin size 2.2				◆			
Volume per passenger 3.3				◆			
Size and number of windows 3.5	◆			◆			
Size and weight of vehicle 4.5	◆	◆	◆	◆	◆	◆	◆
Interfaces							
Systems for communication, navigation, landing 4.6	◆		◆	◆			
Spaceship mated with launch platform 5.5.	◆			◆	◆		
Constraints							
Acceleration force 3.3		◆					
Compliance with safety requirements 5.2			◆	◆			
Quality, Support, etc.							

Stage 2: Preliminary Design

Requirements Allocation

- Since each CI represents something that will ultimately be a physical item—a piece of hardware, software, etc., assignment of functional requirements to CI's represents a subtle change in thinking—from *what* must be done to *how* the system will do it.
- Allocation of requirements results in setting specific technical targets for each CI.
- Achieving these targets is critical, so the estimated and actual performance of each CI is closely monitored.
- If it becomes clear that a target cannot be achieved, then the allocations are readjusted.

Stage 2: Preliminary Design

Interfaces

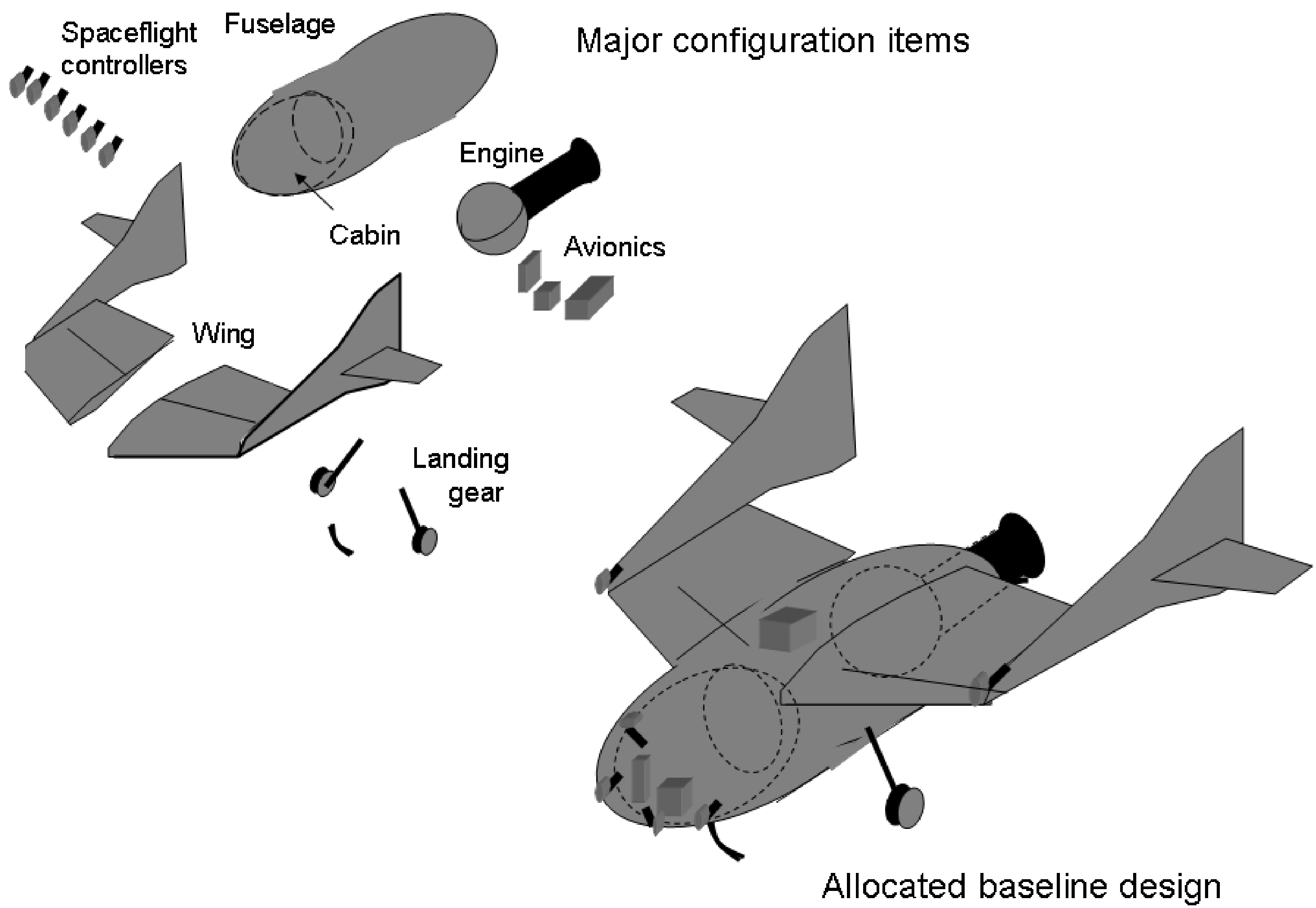
- All subsystems *rely on outputs* of other functions, and *provide inputs* to still other functions—they *interface*.
- All interfaces must be identified and requirements set for each.
- FFBDs provide information about interfaces. Each FFBD arrow represents interface between functions.
  - Physical—connections, joints, supports, pipes
  - Electronic—analog or digital signals, electricity
  - Hydraulic/pneumatic—liquid or gas
  - Software—data
  - Environment—temperature, pressure, humidity, radiation, magnetism
  - Procedural—completion of a procedural step so another next step can begin
- Identifying the interfaces is necessary for setting input-output requirements of every subsystem and element.

Stage 2: Preliminary Design

Synthesis and Evaluation

- Designing each CI and its elements involves choosing design alternatives and deciding to use an OTS designs or products, or to create new ones.
- Selection of alternatives considers the synthesis of components—the impact of each design decision on other components and the overall system.
- With each decision, the form and configuration of the CI's evolves and the appearance of the system takes shape.
- By the end of preliminary design: system *architecture* will have been established; system-level requirements will have been allocated among the CI's.
- The architecture and allocation form the "***allocated baseline***" design

Example: CI's and Allocated Baseline Design



Stage 3 of the Systems Engineering Process: Detailed Design and System Development

Project effort moves from "concepts on paper" to a design ready to be built.

- Decisions made about whether subsystems/ components will be manual, automatic, electronic, mechanical, hydraulic, etc.
- Available, OTS components are selected based on surveys or comparison tests in a laboratory
- Newly developed components are tested experimentally using models to verify the designs
- The system is checked under a variety of conditions and operational modes.
- Modifications are made to remove oversights and deficiencies and to improve the system.
- The capability (facilities and resources) to produce the system (the "process design") is developed

Stage 4 of the Systems Engineering Process: System Construction and/or Production Stage

Begins as soon as the design is approved and "frozen."

- During this stage the system is either
  - (1) mass produced
  - (2) produced in limited quantities with different features or
  - (3) built as a single item.
- The stage involves acquiring materials, managing inventory, and controlling production/construction operations to uphold performance, quality, reliability, safety, and other requirements.

Stage 5 of the Systems Engineering Process: System Operation and Support Phase

Customer operates the system; system ultimately wears out or becomes obsolete.

- Developer might provide support; e.g.:
  - in deploying, installing, and checking out the system
  - assisting in day-to-day operation with field service and maintenance support
  - Modifying or enhancing the system
  - Closing or phasing out, and disposing of the system at the end of its life cycle.
- Close-out and disposal of the system can be a major consideration in the design and operation of the system, especially so for systems that have potential to degrade the surrounding environment.