Chapter 2

System Science & Engineering

System Thinking: https://www.youtube.com/watch?v=V38HrPnYkHI

Systems Engineering: https://www.youtube.com/watch?v=5QENN-D7cfo

Bringing Systems to Being
Chapter 2

- The Engineered System
  - Characteristics of the engineered system
  - Product and system categories
  - Engineering the product and the system
  - Engineering for product competitiveness
- The System life cycle engineering
  - The product and system life-cycles
  - Designing for the life-cycle
- The systems engineering process
  - Life-cycle process phases and steps
  - Other systems engineering process models
- System design consideration

- New and emerging technologies are expanding physically realizable design options and capabilities for developing more cost-effective systems,
- Introducing a technologically based interdisciplinary process encompassing an extension of engineering through all phases of the system life cycle:
    - Design and development, production or construction, utilization and support, and phase-out and disposal
- Upon completion: in-depth understanding of:
    - Engineering the relationships among systems to achieve sustainability of the product and the environment, synergy among human-made systems and continuous improvement
    - System design evaluation and the multiple-criteria domain
    - Integration and iteration in systems design, invoking the major activities of synthesis, analysis, and evaluation.
    - The importance of investing in systems thinking and engineering early in the life cycle, and the importance thereto of systems engineering management
    - Proper and timely implementation of systems engineering and analysis

Organized Technological Activities for Bringing Engineered Systems into Being

- Characteristics of Engineered Systems
  - *Functional purposes* in response to identified needs and ability to achieve stated *operational objectives*
  - *Brought into being* and *operate* over a life cycle: Identification of needs and ending with phase-out and disposal
  - Composed of combination of resources: facilities, people, equipment, software, money, etc.
  - Composed of *subsystems* and related *components* that interact with each other to produce a desired system response and behavior
  - A part of a *hierarchy* and are influenced by external factors
  - *Embedded* into natural world and *interact* with it

Bringing Systems to Being continued

- Product and System Categories
  - Systems are known by their products
    - Examples:
      - Manufacturing systems
      - Transportation systems
      - Construction systems
- Engineering the product and the system
  - People often acquire diverse products to meet specific needs without companion contributing systems to *ensure the best overall results* and *without considering the effects* of the products on the environment, on humans, and other human-made systems
  - Proper application of systems engineering and analysis ensures *timely and balanced evaluations of all issues*.

- Engineering the product and the system (Cont.)
  - Engineering activities purpose of the design and analysis is to determine how physical and conceptual factors may be altered to create the most utility for the least cost:
    - Product cost
    - Product service cost
    - Social cost
    - environmental cost
  - Classical engineering focuses on physical factors (selection and design of physical components and their behaviors and interfaces)
  - Achieving the best overall results requires initially:
    - Conceptual factors such:
      - Needs
      - Requirements
      - Functions
  - Engineering the system and product requires an interdisciplinary approach embracing both the product and associated capabilities: system maintenance, support, logistics, connected system relationships, and phase-out and disposal

- Engineering for product competitiveness
  - Intensifying international competition, producers seek ways to gain a sustainable competitive advantage in the marketplace
  - Human and physical resources dwindling
  - Industrial base is expanding
  - International competition increasing rapidly
  - Organizations downsizing
    - Seeking to improve their operations
    - Considering international partners
  - Acquisitions, mergers, and advertising campaigns unable to create the wealth for the long-term health of the organization

Economic Competiveness

- It is essential to be competitive
- Engineering with an emphasis on economic competitiveness MUST become *coequal* with concerns for advertising, production distribution, finance and the like
- To ensure competitiveness engineering MUST become closely associated with economic and economic feasibility
- Accomplished through a *system life-cycle approach to engineering*

- ***A competitive economy, we believe, is a productive one. And productivity leads to growth, which leads to income levels and hopefully, at the risk of sounding simplistic, improved well-being.***
- *https://www.weforum.org/agenda/2017/09/what-is-economic-competitiveness/*

Using a system approach

- Improving product definition
- Applying total system approach & product life cycle to the product or service
- Considering the system hierarchy & interaction
- Organizing integration of related disciplines & a method to review & evaluate

System Life-Cycle Engineering

- Properly functioning system that is effective and economically competitive CAN NOT be achieved through effort applied largely after it comes into being
  - **Responsibility for life-cycle engineering becoming the central engineering focus**
  - **Largely neglected in the past**

System Life-Cycle Engineering (Cont.)

- **The Product and System Life Cycles**
  - The life cycle phases are classified as:
    - Acquisition
    - Utilization
  - To recognize *producer* and *customer activities*
  - Product life cycle begins with
    - Acquisition phase
      - Need identification
      - Conceptual design
      - Detail design
      - Production or construction
    - Utilization phase
      - Usage, maintenance, phase out, & disposal. Figures 2.1 & 2.2

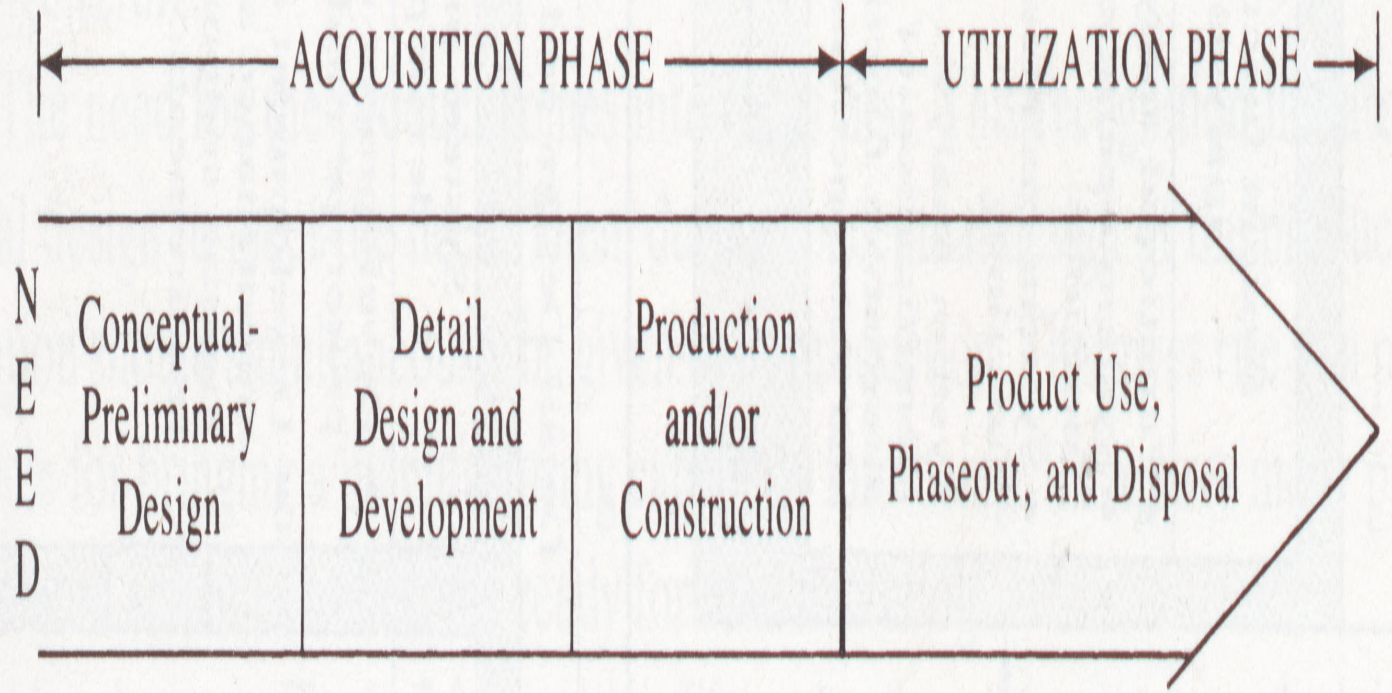
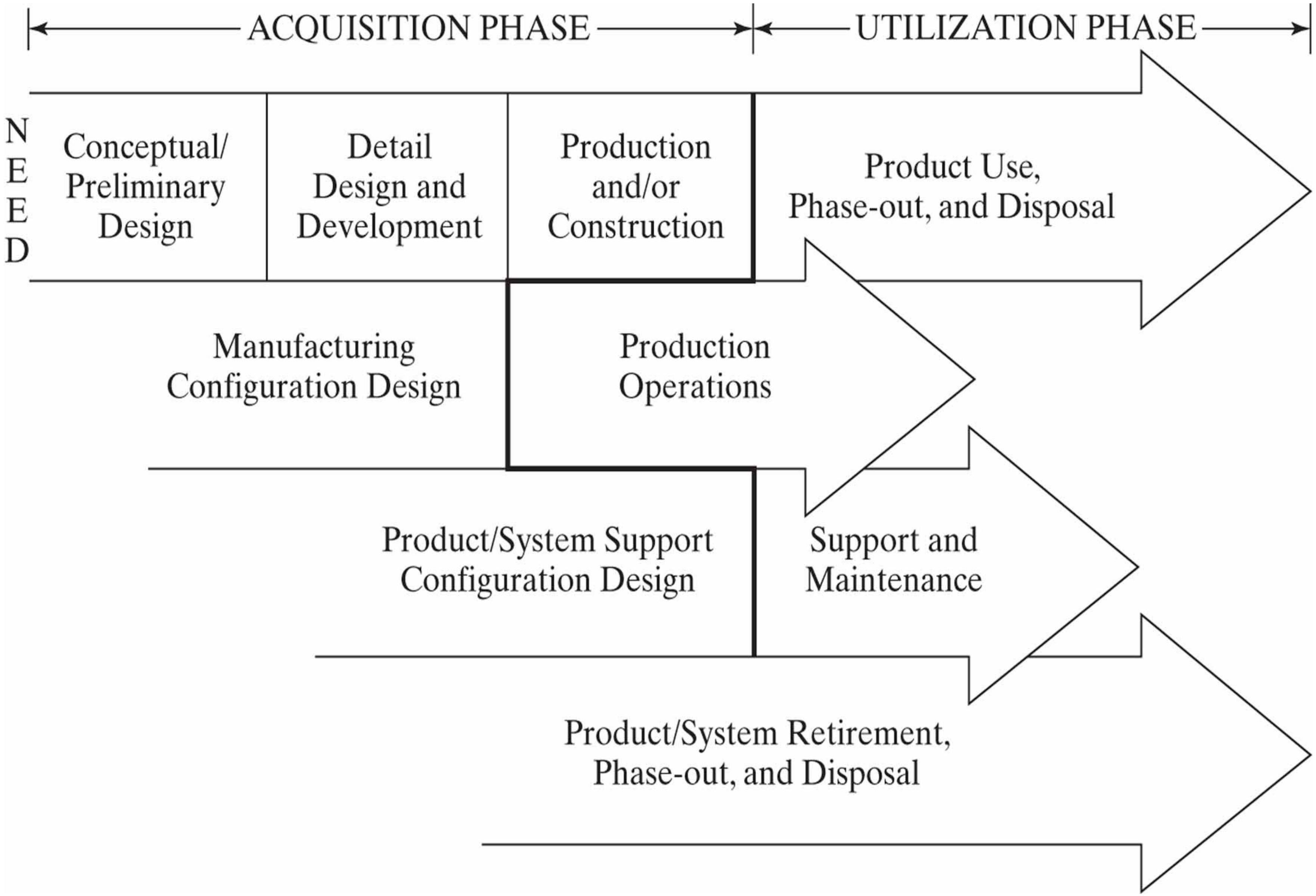


Figure 2.1 The product life cycle.

System Life-Cycle Engineering (Cont.)

- *System life cycle engineering* goes beyond the *product life cycle*
  - Must concurrently embrace the life cycle of*:*
    - Production or construction subsystem
    - Maintenance and support subsystem
    - Retirement, phase-out, reuse, and disposal
- The overall system is made up of four concurrent life cycles progressing in parallel (Figure 2.2)
  - The NEED for the product comes first. Initiate the conceptual design
  - During conceptual design, consideration should be given to its production
  - Give rise to concurrent life cycles


ACQUISITION PHASE
UTILIZATION PHASE
NEED
Conceptual/ Preliminary Design
Detail Design and Development
Production and/or Construction
Product Use, Phase-out, and Disposal
Manufacturing Configuration Design
Production Operations
Product/System Support Configuration Design
Support and Maintenance
Product/System Retirement, Phase-out, and Disposal

System Life-Cycle Engineering (Cont.)

- As each of the life cycles is considered, *design features* should be integrated to facilitate : Examples
  - Phase- out, regeneration, or retirement having *minimal impact* on interrelated systems
  - End of life recyclability, reusability, and disposability contribution to environmental sustainability
  - Readiness of the system for regeneration by addressing changes in requirements: increase in complexity, planned new technologies, new regulations, market expansion, others
  - Addressing compatibility issues during conceptual design to avoid or minimize the need for system or product redesign

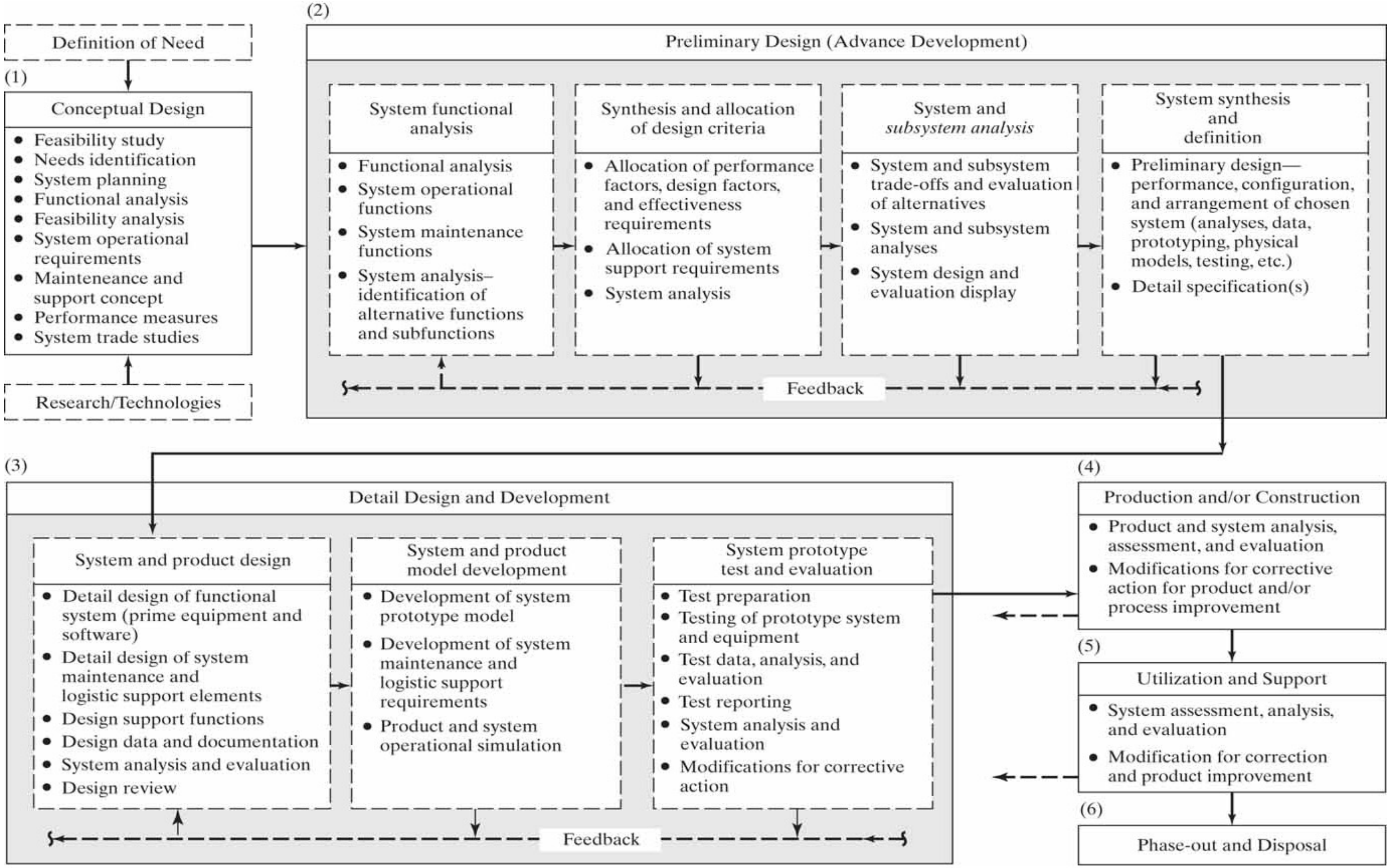
System Life-Cycle Engineering (Cont.)

- **Designing for the Life Cycle**
  - Life cycle guided design is simultaneously responsive to:
    - Customer needs (requirements expressed in functional terms)
    - Life cycle outcomes

<u>*Note:*</u> *Design should not only transform a need into a system configuration but also ensure design's compatibility with related physical and functional requirements*

  - Design should consider further operational outcomes:
    - Productivity, reliability, maintainability, usability, supportability, serviceability, disposability, sustainability, and others
- Detailed activities in Figure 2.3
  - The progression is *iterative* from left to right and *not serial*
  - Details and levels may vary depending on the product or construction

Figure 2.3 Technological activities and interactions within the system life-cycle process.



System Life-Cycle Engineering (Cont.)

- **Designing for the Life Cycle (Cont.)**
  - Mapping Figure 2.2 to Figure 2.3
    - Acquisition phase -> Blocks 1-4
    - Utilization phase -> Blocks 5 – 6
    - Design phase -> Blocks 1-3
    - Startup phase -> Blocks 4
    - Operation phase -> Block 5
    - Retirement phase -> Block 6

<u>Note:</u> The communication and coordination needed to design and develop the product and the relationships with interrelated systems, and all the related activities is *not easy to accomplish.*

Progress in this area is facilitated by technologies: Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM)

System Life-Cycle Engineering (Cont.)

- Progress in this area is facilitated by technologies: Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM

- CAM can automatically translate CAD drawings into manufacturing instructions for numerically controlled equipment

<u>Note:</u> Many firms have chosen to design with life cycle in mind

Designing for the Life Cycle – The System Engineering Process

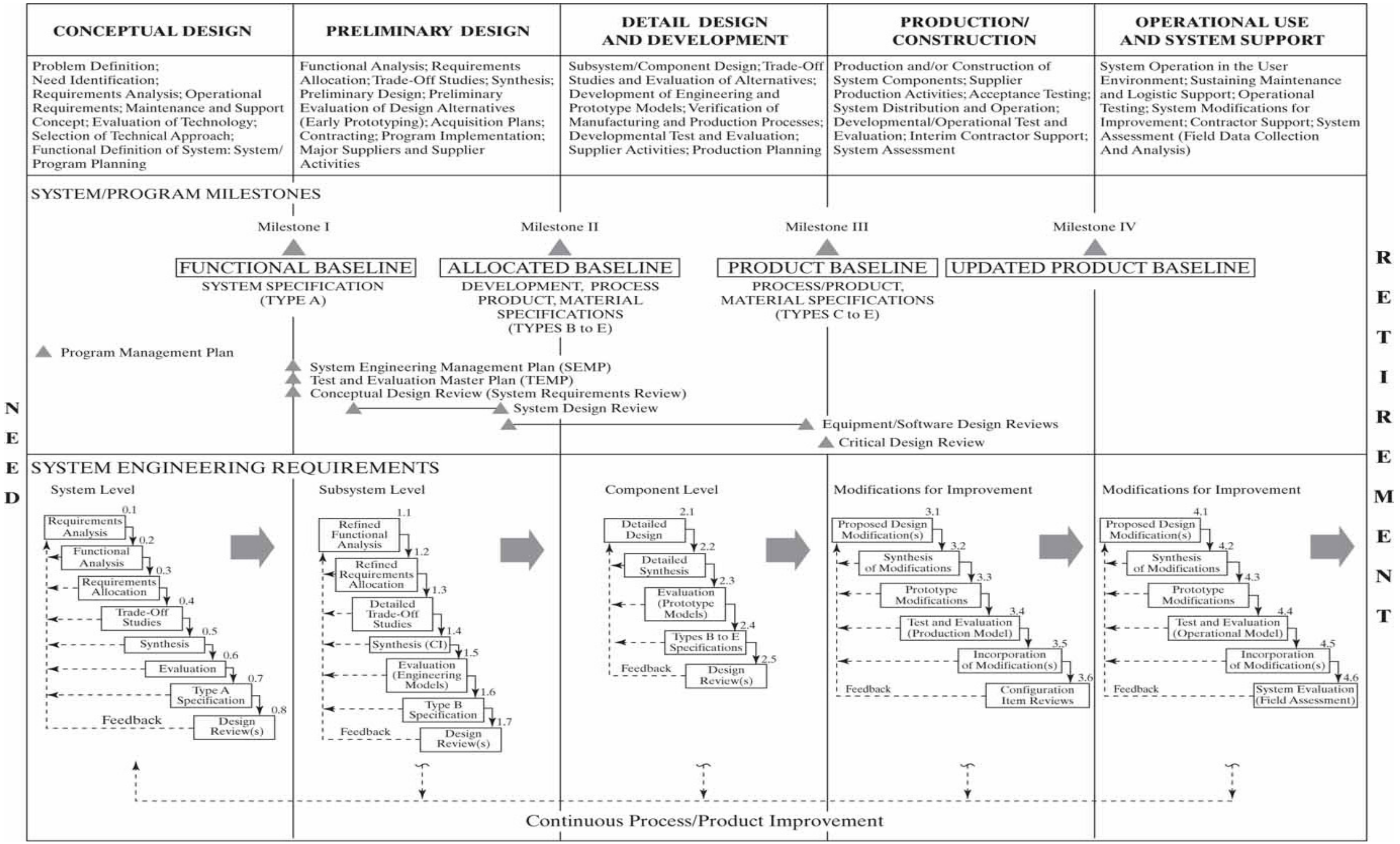
- The actual implementation of the systems engineering varies from team to the next
- The process and steps used depend on the nature of:
  - System application
  - backgrounds and experiences of the individuals on the team
- Establishing a BASELINE as a common frame of reference is important for improving communication and understanding

Designing for the Life Cycle – The System Engineering Process

- **Life-cycle Process Phases and Steps**
  - Figure 2.4 illustrates the *major life-cycle process phases* and *selected milestones* for generic system
  - This model serves as a *frame of reference* for now and onward
  - During the conceptual design, the scope of needs may contract or expand but the scope should be *stabilized as early as possible* preferably based on *an evaluation of value and cost by the customer*

<u>Note:</u> Program phases in Figure 2.4 are not intended to convey specific tasks, milestones, timelines, or funding levels. They very form application to the next.

Figure 2.4 System process activities and interactions over the life cycle.



Designing for the Life Cycle – The System Engineering Process

- (Block 0.1-0.8, block 1.1-1.7, and block 2.1-2.5) to be iterative
- Providing a *top-down definition of the system*, and then proceeding down to the subsystem level and below as necessary
  - Identifying the *“Whats”* from a requirements perspective
  - Block 0.2 defines the system in *functional terms*
  - *“Whats”* are translated into an applicable set of *”hows”* through the iterative process of functional partitioning and requirements allocation

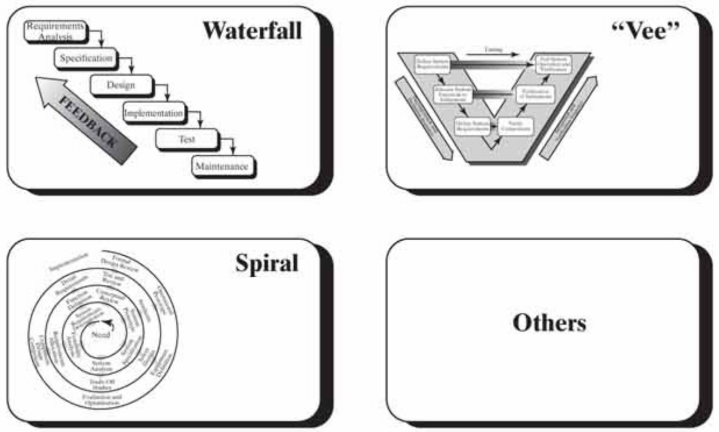
Designing for the Life Cycle – The System Engineering Process

- Evolutionary design and development process
  - Blocks 1.1-1.7 are an evolution from blocks 0.1-0.8
  - Blocks 2.1-2.5 are from blocks 1.1-1.7
  - Blocks 3.1-3.6 are from 2.1-2.5

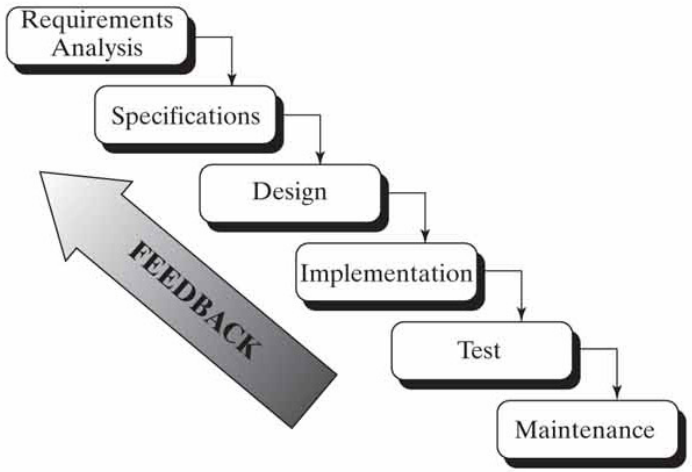
- With appropriate feedback and design refinement, *the process should eventually converge to a successful design*
- More details of the system engineering process in Part II (Chapters 3-6)
- Figure 2.4 is not intend to emphasize any particular mode: Waterfall, Spiral model, Vee model, or equivalent

Figure 2.5 Some systems engineering process models (sheet 1

(a) **System Process Models**



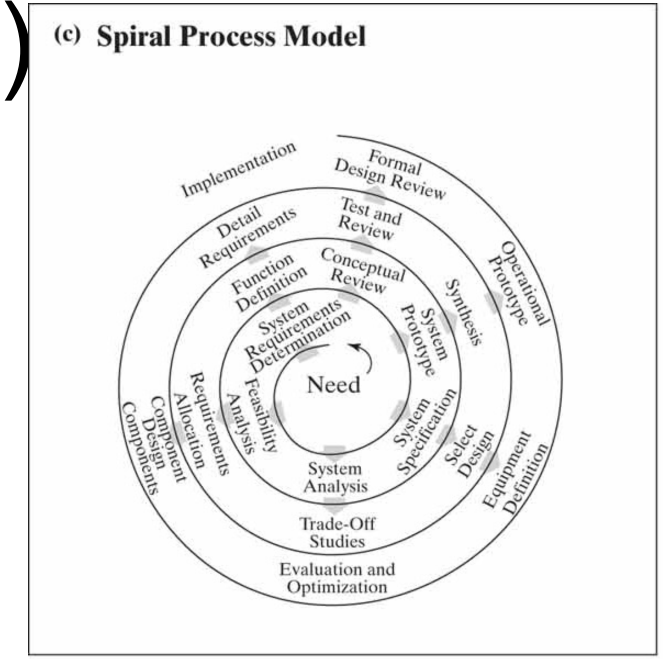
(b) **Waterfall Process Model**

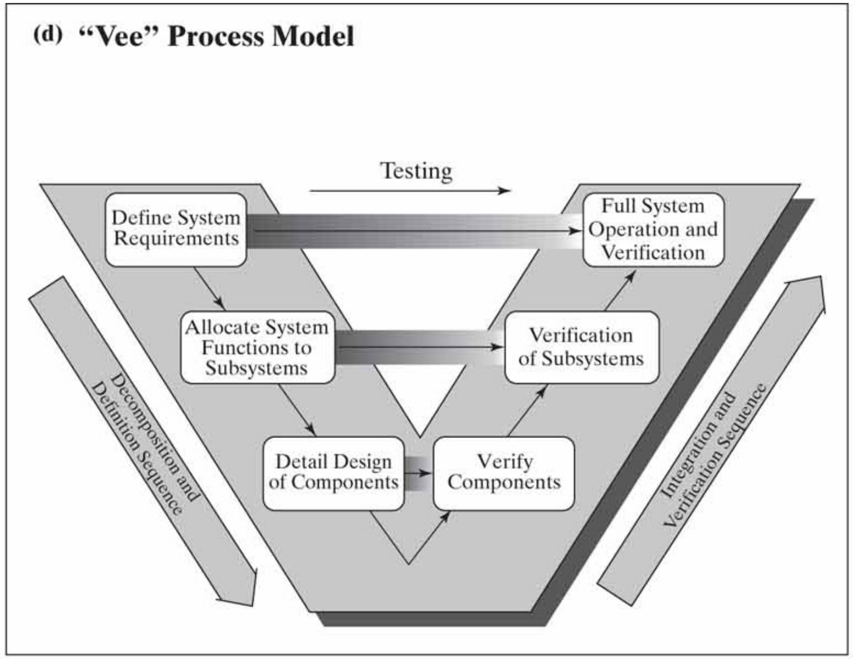


- It is observed that the preference expressed by individuals and groups for one of the system models is subjective.
- A study of the literature and current practice is needed to identify which model fits a specific situation best. Refer to Appendix G.

- The waterfall model, introduced by Royce in 1970, initially was used for software development. This model usually consists of five to seven series of steps or phases for systems engineering or software development. Boehm expanded this into an eight-step series of activities in 1981.
- A similar model splits the hardware and software into two distinct efforts. Ideally, each phase is carried out to completion in sequence until the product is delivered. However, this rarely is the case. When deficiencies are found, phases must be repeated until the product is correct.

Figure 2.5 Some systems engineering process models (sheet 2)





- The spiral process model of the development life cycle (developed by Boehm in 1986 using Hall's work in systems engineering from 1969) is intended to introduce a risk-driven approach for the development of products or systems.
- This model is an adaptation of the waterfall model, which does not mandate the use of prototypes. The spiral model incorporates features from other models, such as feedback, etc.
- Application of the spiral model is iterative and proceeds through the several phases each time a different type of prototype is developed. It allows for an evaluation of risk before proceeding to a subsequent phase.

- Forsberg and Mooz describe what they call "the technical aspect of the project cycle" by the "Vee" process model. This model starts with user needs on the upper left and ends with a user-validated system on the upper right.
- On the left side, decomposition and definition activities resolve the system architecture, creating details of the design. Integration and verification flows upward to the right as successively higher levels of subsystems are verified, culminating at the system level.
- Verification and validation progress from the component level to the validation of the operational system. At each level of testing, the originating specifications and requirements documents are consulted to ensure that component/subsystems/system meet the specifications.

Assignment 2

1) Based on your selected team project, describe the enabling system that is required to bring it into being, and explain the importance of engineering the system and the product together
2) Describe some of the interfaces and interactions between the life-cycle of the system and the product life-cycle
3) Describe the applicable life-cycle phases and activities, tailoring your description to to your project
4) Of the models Waterfall, Vee model, spiral model, pick the one you prefer and explain