Chapter 5

Detail Design and Development

Detail Design and Development

- The ***detail design and development*** phase of the system life-cycle is a continuation of the iterative process Fig. 2.3 and 2.4
- The establishment of a top-level functional baseline and the preparation of the system specification (Type A) ***leads to the definition and development of subsystems and major elements*** as described in Chap. #4.
- ***Foundation of the detailed design*** consists of:
    - Functional Analysis
    - Allocation of of design-to requirements below the system level
    - Synthesis and trade-off studies
    - Lower-level specifications (Types B-E)
    - Conduct of formal reviews
- With the ***functional baseline*** and ***allocated baseline*** as an output of the conceptual system design phase, the design team may proceed in the realization of ***specific components and the make-up of the system*** configuration at the lowest level in hierarchy.

Detail Design and Development

- Realization includes the accomplishment of activities that:
  - Describe subsystems, units, assemblies, lower-level components, software modules, people, facilities, etc.
  - Prepare specifications and design data for all system components
  - Acquire and integrate the selected components into a final system configuration
- This chapter addresses ***8 essential steps in the detail design and development:***
  - Developing design requirements for all lower-level components of the system
  - Implementing the necessary technical activities to fulfill all design objectives
  - Integrating system elements and activities
  - Selecting and utilizing design tools and aids
  - Preparing design data and documentation
  - Developing engineering and prototype models
  - Implementing a design review, evaluation, and feedback capabilities, and
  - Incorporating design changes as appropriate

Note: As a learning objective, the intend is to provide a relatively ***comprehensive approach*** that addresses ***the detailed aspects of design***

Detail Design Requirements

- Specific requirements at this stage are derived from the system specification (Type A) and evolve through applicable lower-level specifications (Types B-E) Fig. 5.1
- Included within these specifications are:
    - Design-Dependent Parameters (**DDPs**),
    - Technical Performance Measures (**TPMs**), and
    - **Supporting design-to criteria** leading to identification of the specific characteristics that must be incorporated into the design configuration of **elements and components**
- This is influenced through the requirements allocation process illustrated in Fig 4.6
    - **Allocated quantitative requirements** will be **met**.

- ***Top-down approach*** for establishing requirements at each level in ***the system hierarchical structure*** Fig. 4.6
- As a learning objective, the intend is to provide a relatively ***comprehensive approach*** that addresses ***the detailed aspects of design***

Figure 5.1 Sequential versus concurrent approaches in system design.

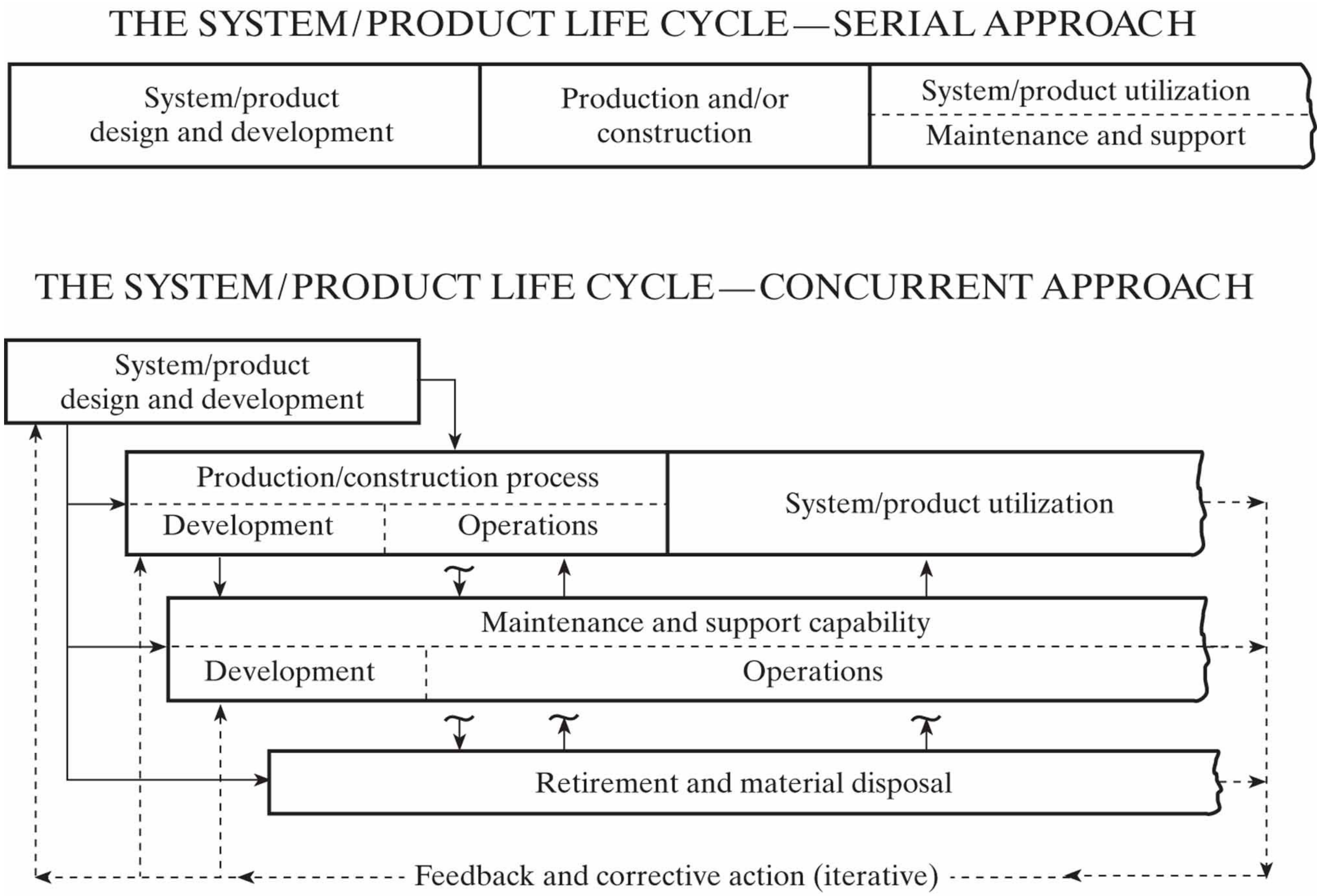
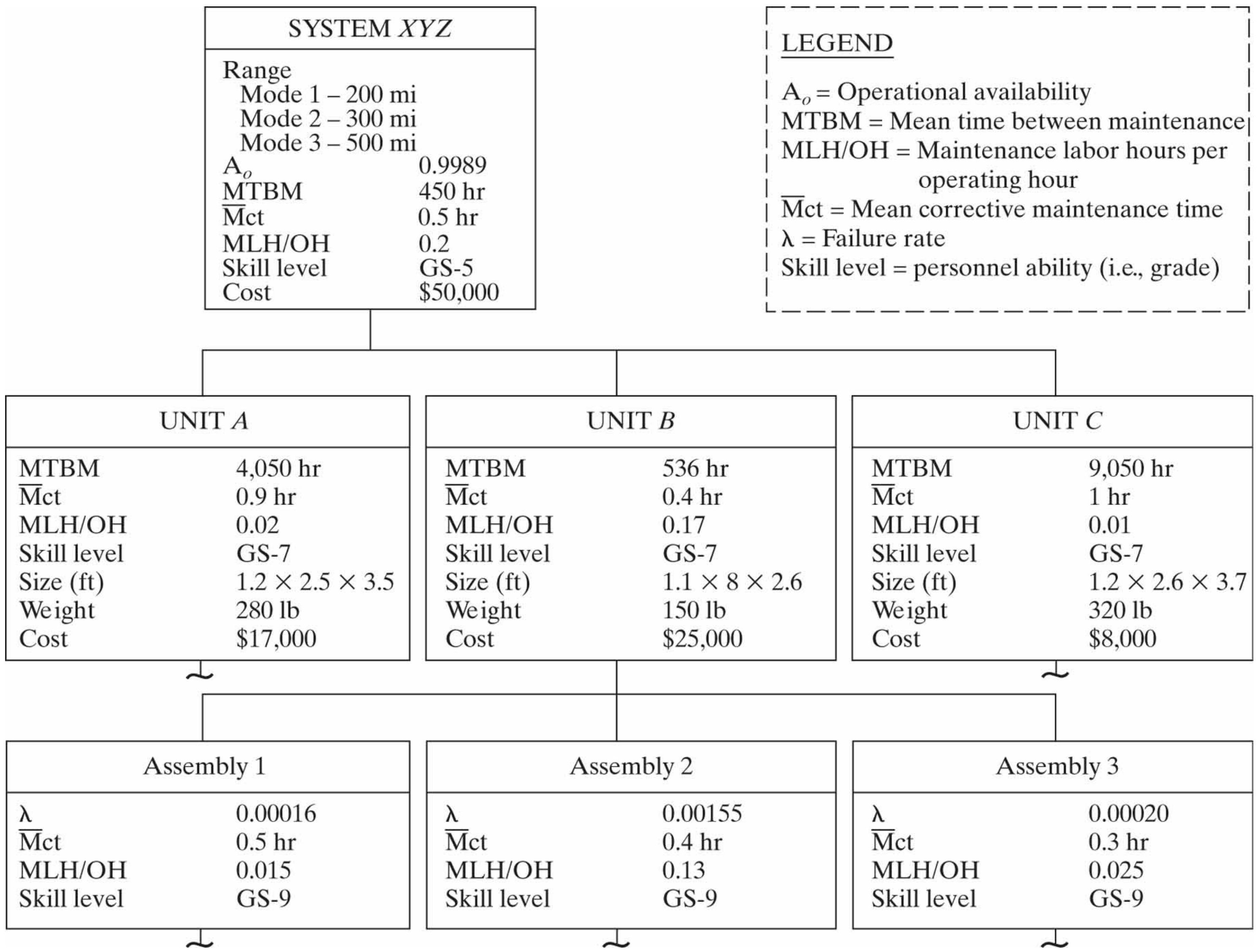


Figure 4.6 System *XYZ* requirements allocation.



Detail Design Requirements

- ***Top-down approach*** for establishing requirements at each level in ***the system hierarchical structure*** Fig. 4.6
- The design process evolves through the iterative steps of:
  - Synthesis,
  - Analysis, and evaluation, and
  - The definition of components leading to the establishment of a ***product baseline*** Fig. 2.4
- At this point, the ***procurement and acquisitions*** of system components begin
- Components are tested and integrated into a ***next higher entity*** (subassembly, assembly, and unit), and
- ***A physical model*** of the system is **constructed** for test and evaluation
- ***Bottom-up Approach***: The integration, test, and evaluation steps constitute a bottom-up approach
- This ***top-down/bottom-up approach*** is guided by the steps in the ***"vee" process model*** Fig. 2.5

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

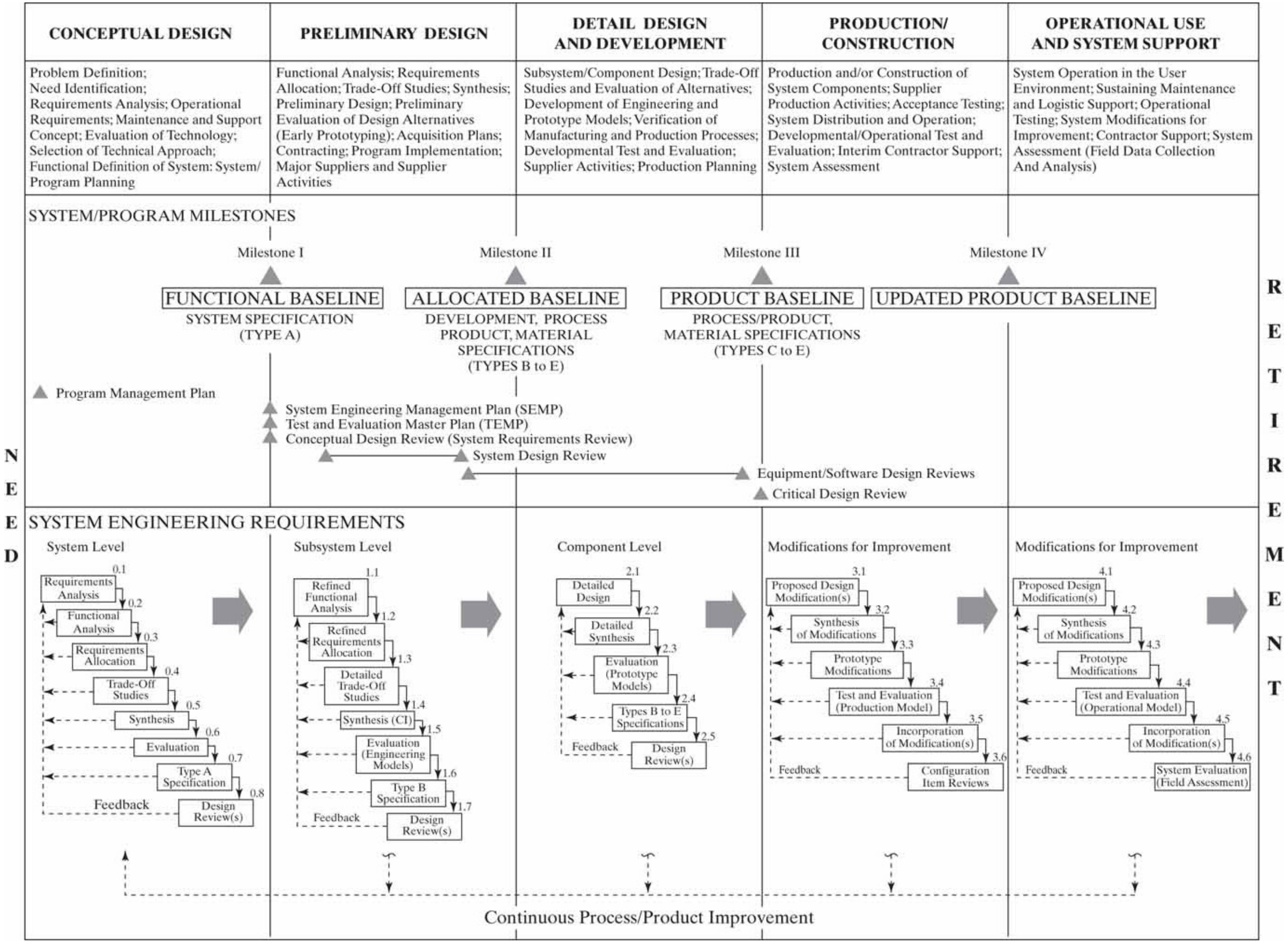
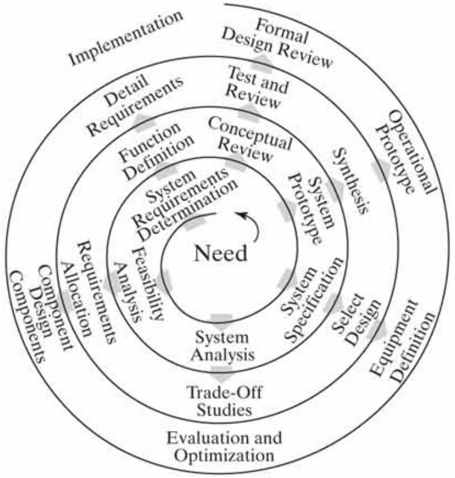


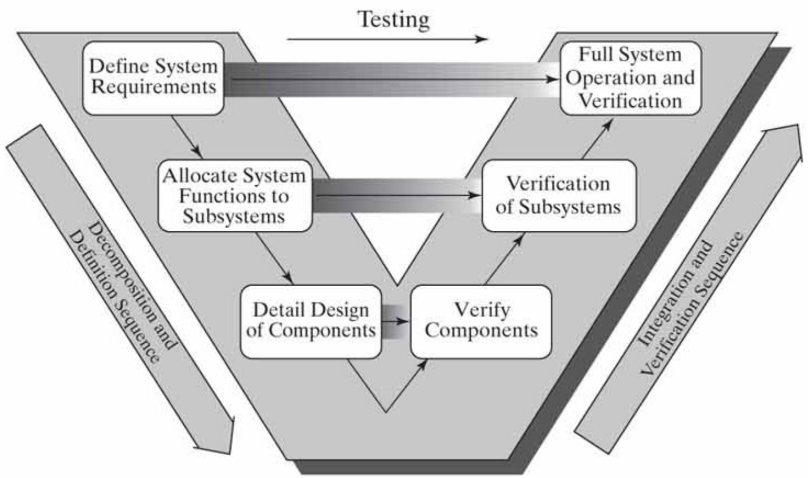
Figure 2.5 Some systems engineering process models (sheet 2).

(c) Spiral Process Model



- 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.

(d) "Vee" Process Model



- 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.

Detail Design Requirements

- **Progressing** through the system design and development process in an **expeditious manner** is **essential** in today's competitive environment
- **Minimizing the time** that it takes from the need identification to ultimate delivery of the system to the customer is **critical**
- This requires that ***certain design activities*** be accomplished on a ***concurrent basis*** Fig. 5.1
- Think in terms of the four life cycles and ***their interrelationships, concurrently and in integrated*** manner in lieu of the sequential approach
- The realization of this necessity became apparent in 1980s
- Resulted in concepts:
    - **Concurrent engineering**
    - **Integrated product development (IPD)**

The Evolution of Detail Design

- The evolution of the detail design is based on the results from the requirements established during:
    - Conceptual design phase
    - Preliminary system design phase

- As an example: **The river crossing**
    - Top level requirements were identified in conceptual design
    - These requirements were decomposed further – next slide
    - Expanded through functional analysis, and allocation of requirements down to major subsystems to include: roadway, railbed, passenger walkway, toll collection facilities, and the maintenance and support infrastructure
    - Then more detailed design-to requirements for various lower-level elements are defined down to foundations, piles, retaining walls, etc. Fig. 5.2

System Design and Feasibility Analysis

- Example

River Crossing Problem

In considering alternative system design approaches, different technology applications are investigated

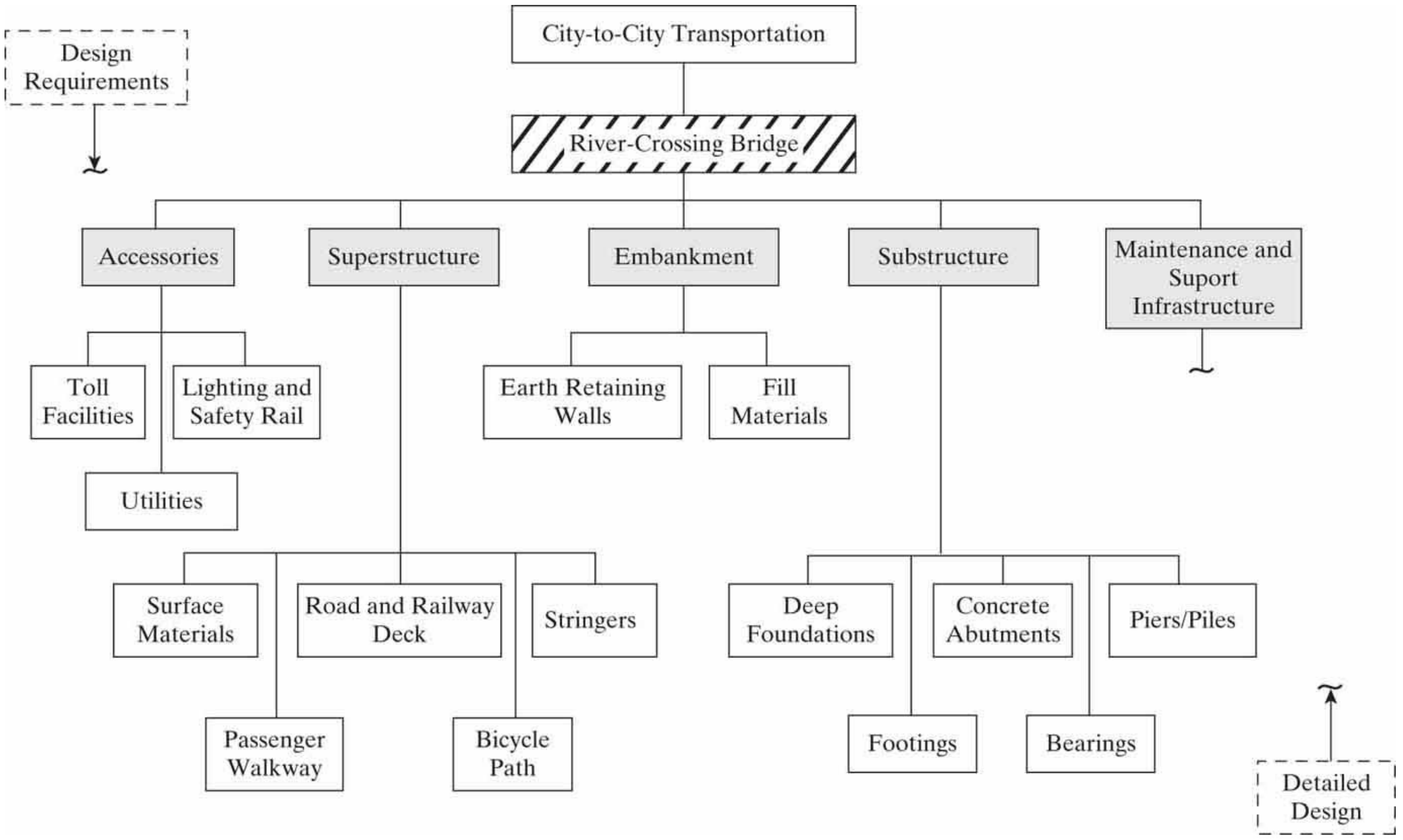
Alternative Design concepts:

- Tunnel under the river
- A bridge
- An airlift capability
- Use of barges and ferries
- Re-routing the river itself

In performing feasibility study, one must address limiting factors such as:

- Geological and geotechnical
- Atmospheric and weather
- Hydrology and water flow
- Meeting the life-cycle cost objectives

Figure 5.2 The top-down/bottom-up design approach for the river crossing bridge system.



The Evolution of Detail Design

- Referring to the Fig 5.2:
    - The design-to ***requirements*** are identified from the top/down with ***cross-hatched block*** defined in conceptual design along with ***allocation and requirements for major subsystems noted by shaded blocks***
    - These requirements are further expanded through functional analysis and allocation during the preliminary design phase to define the specific requirements for the lower-level elements of the bridges represented by the white blocks

Note: The ***basic requirements*** are driven from top/down, while the ***detailed design*** is accomplished from bottom-up, Fig. .10 – Block 5

- Having established the basic top-level requirements for the overall system as in Chapter 3 and the preliminary design requirements as in Chapter 4, this point forward is ***evolutionary***
- The overall objective is to integrate the various elements into a final system configuration Fig. 5 .3
- ***Detail design evolution*** follows the basic sequence of activities in Fig. 5.4.
- The process is iterative
- There are ***"checks and balances"*** in the form of ***reviews at each stage of design progression*** and ***feedback loop*** allows for corrective action

Figure 2.10 Systems engineering morphology for product realization.

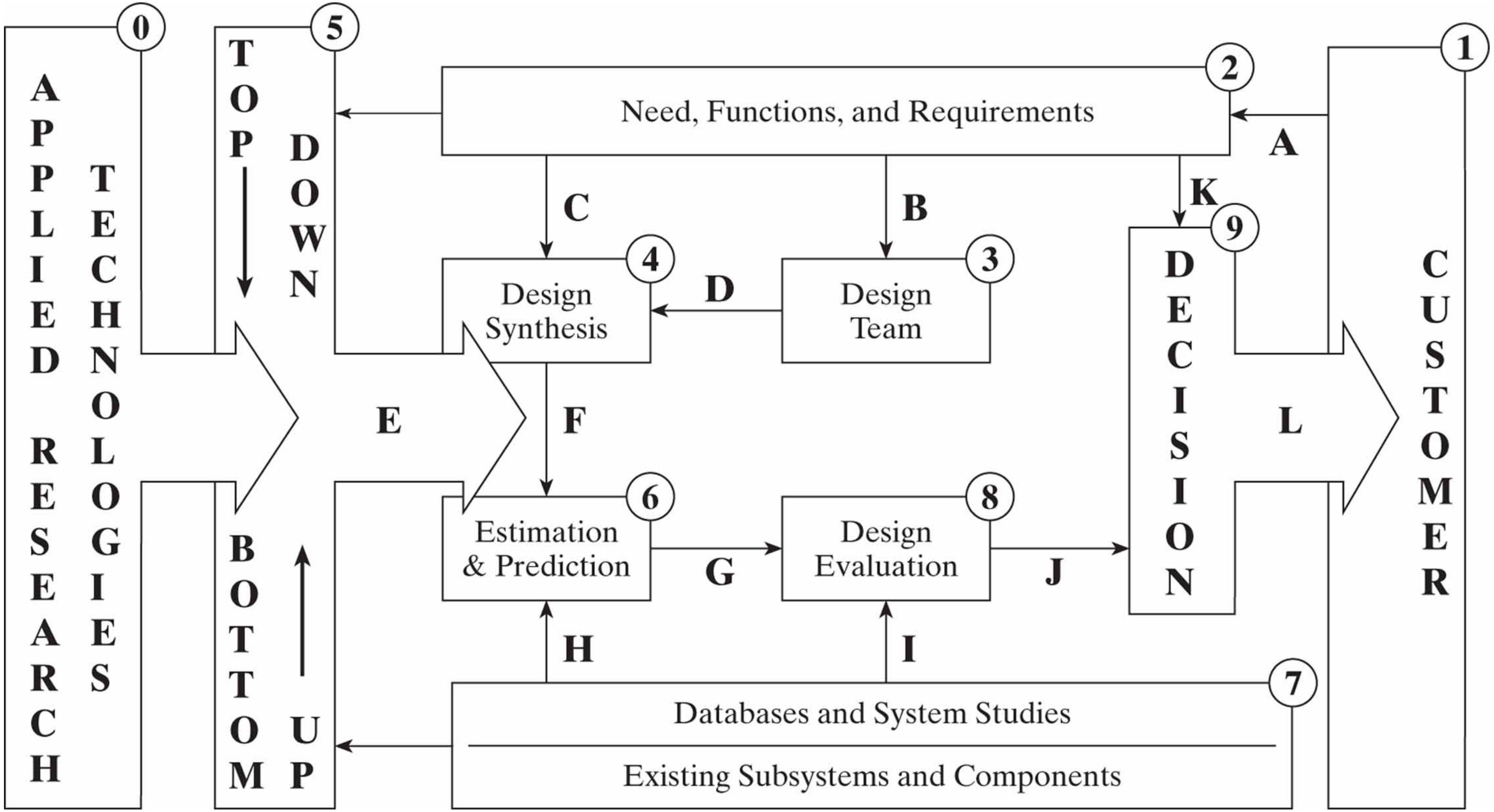


Figure 5.3 The integration of system elements.

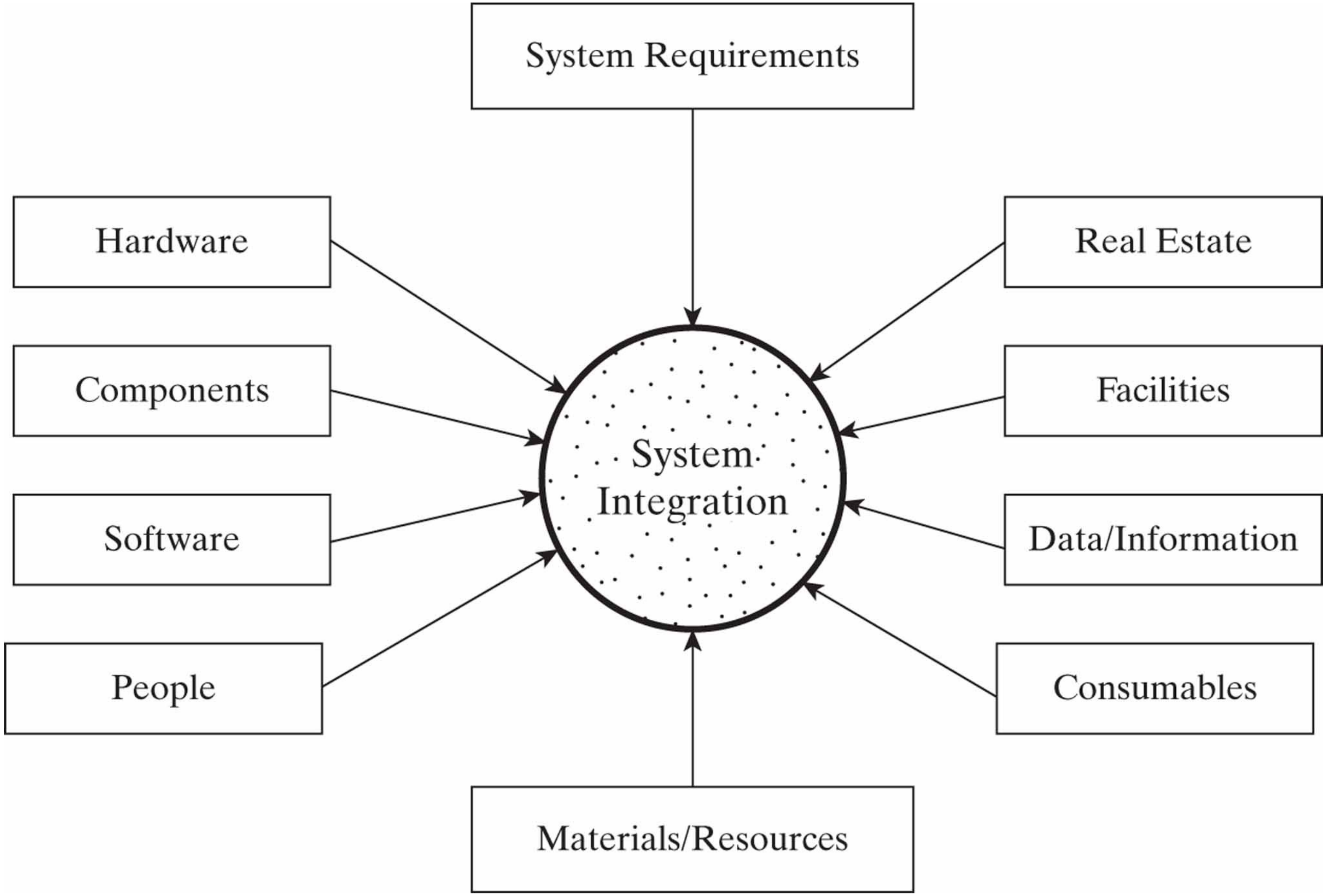
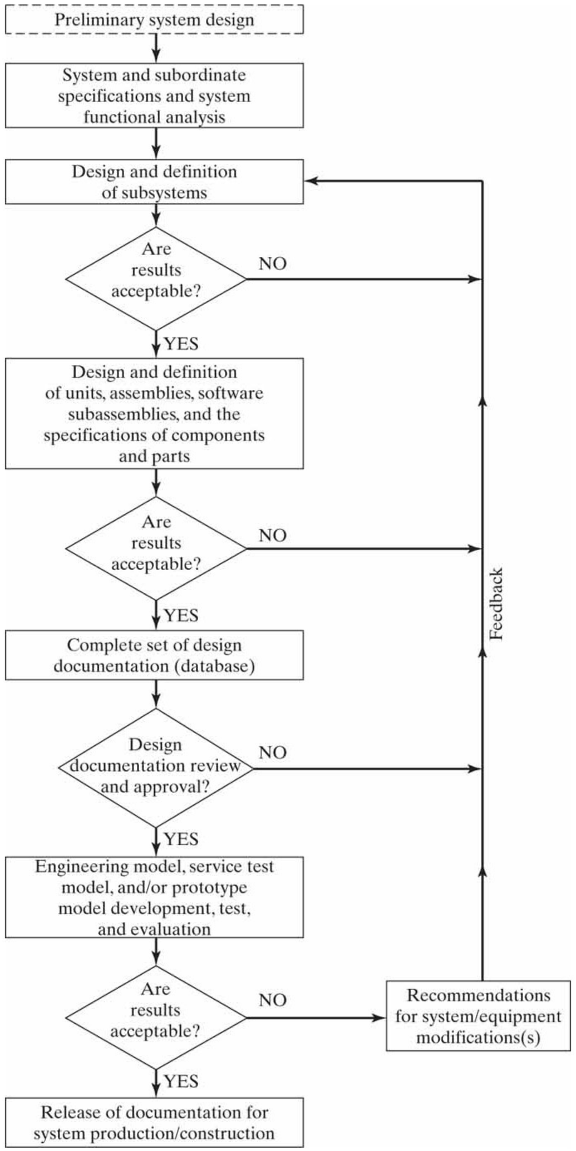


Figure 5.4 Basic design sequence with feedback.



The Evolution of Detail Design

Note:

The ***results*** are practically ***useless unless*** properly documented, so that others can first understand what is being conveyed and then be able to translate and convert the output into an entity that can be constructed (one bridge) or produced in multiple quantities.

Integrating System Elements and Activities

- The objective is to conduct the necessary ***trade-off analyses*** to determine the best way to respond to the ***hows*** – Fig 3.25 and Fig. 4.6
- The designer must decide how best to meet the need in selecting a specific approach in responding to hardware need, software need, and so on
- There are alternative approaches in selecting a specific resource Fig. 5.5 with following the steps (in order of precedence):
    - Select standard component – a commercial off-the-shelf (COTS) item (reduced cost, proper maintenance support will be available)
    - Modify an existing COTS item – Care must be taken
    - Design and develop a new and unique component to meet a specific functional requirement

- The ***most cost effective solution*** seems to favor the ***utilization of COTS components*** as the acquisition cost, item availability time, and risks are likely to be less

Figure 3.25 The functional breakdown of the system into components.

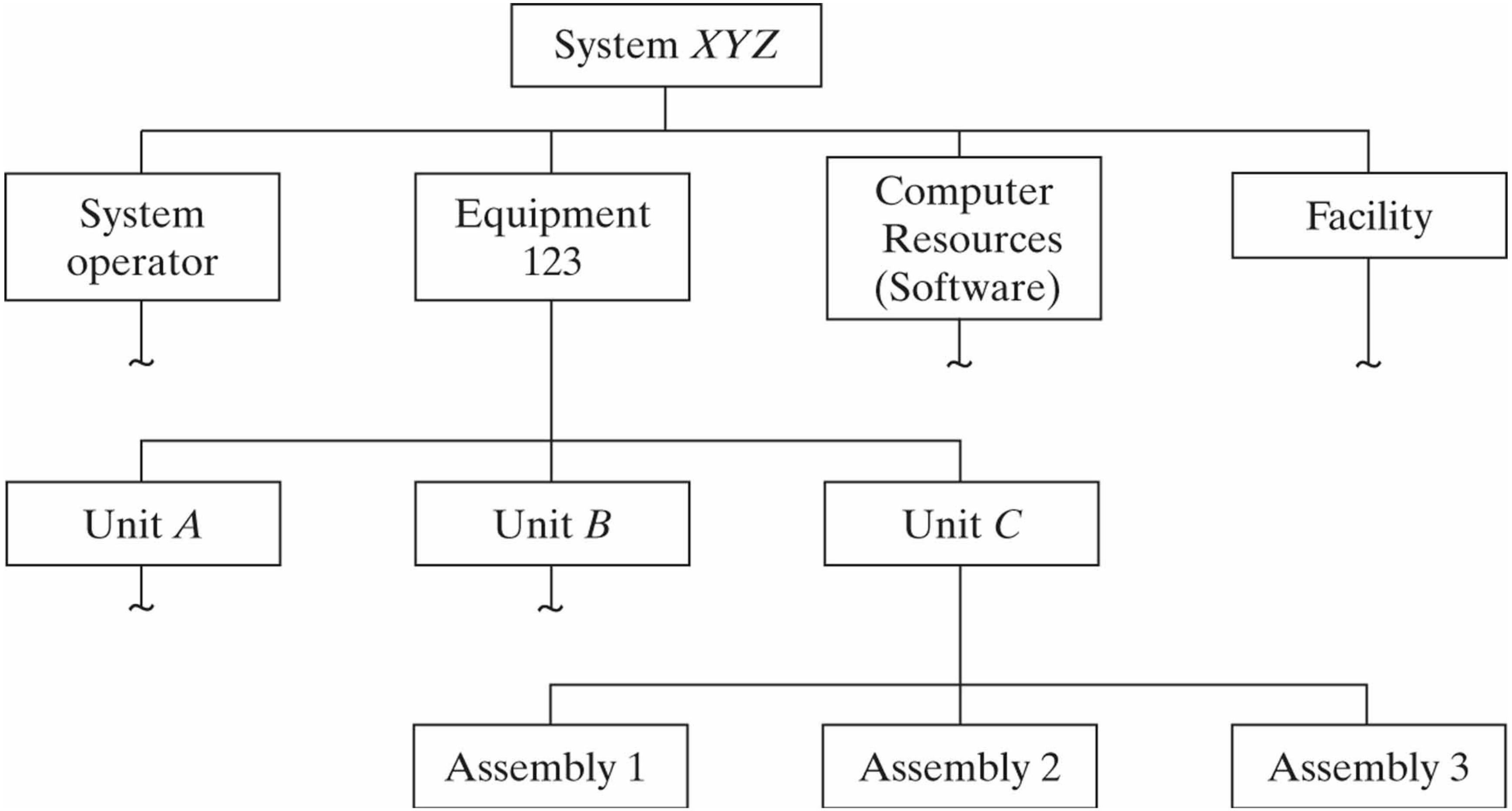


Figure 5.5 Alternative approaches in the selection of resources.

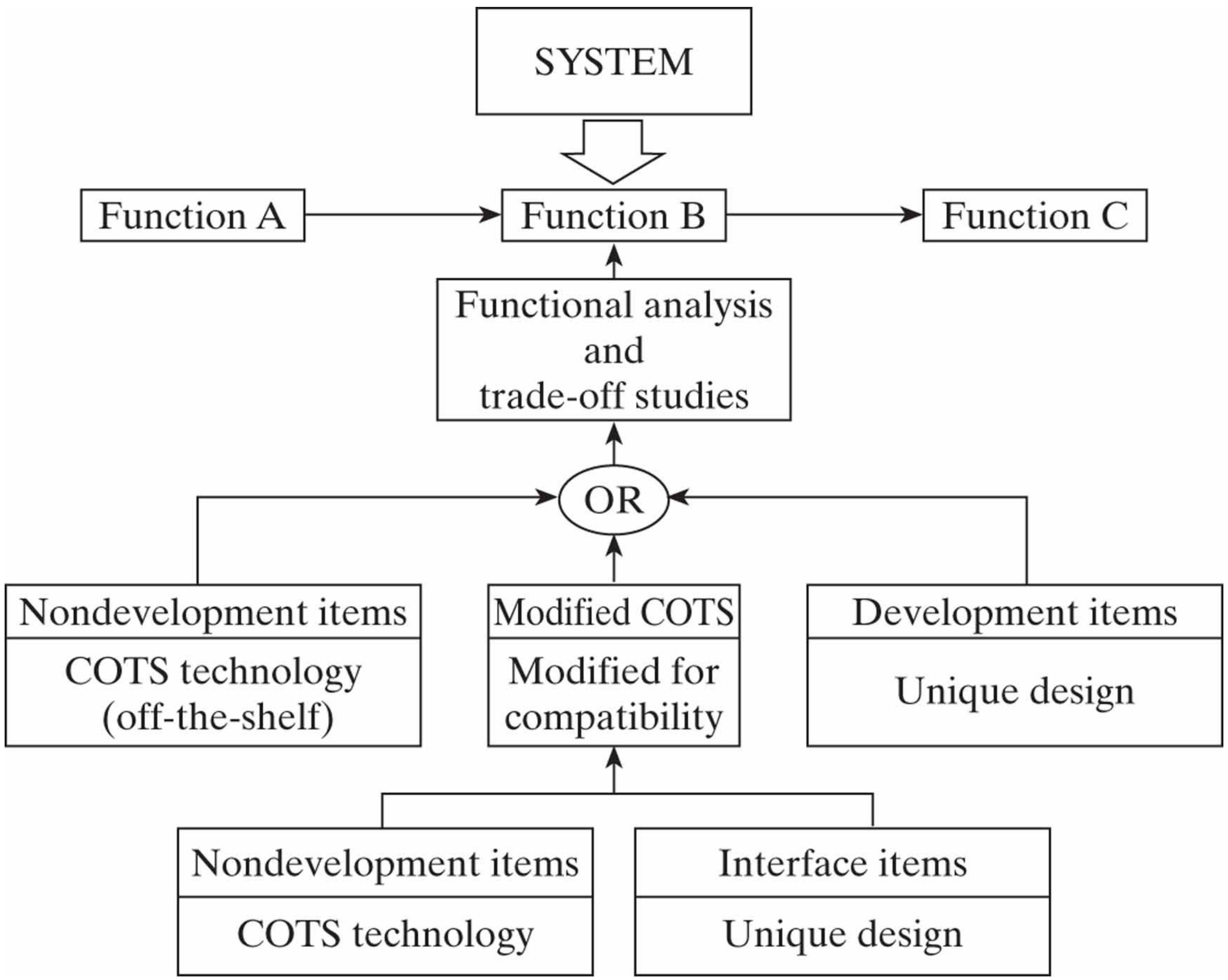
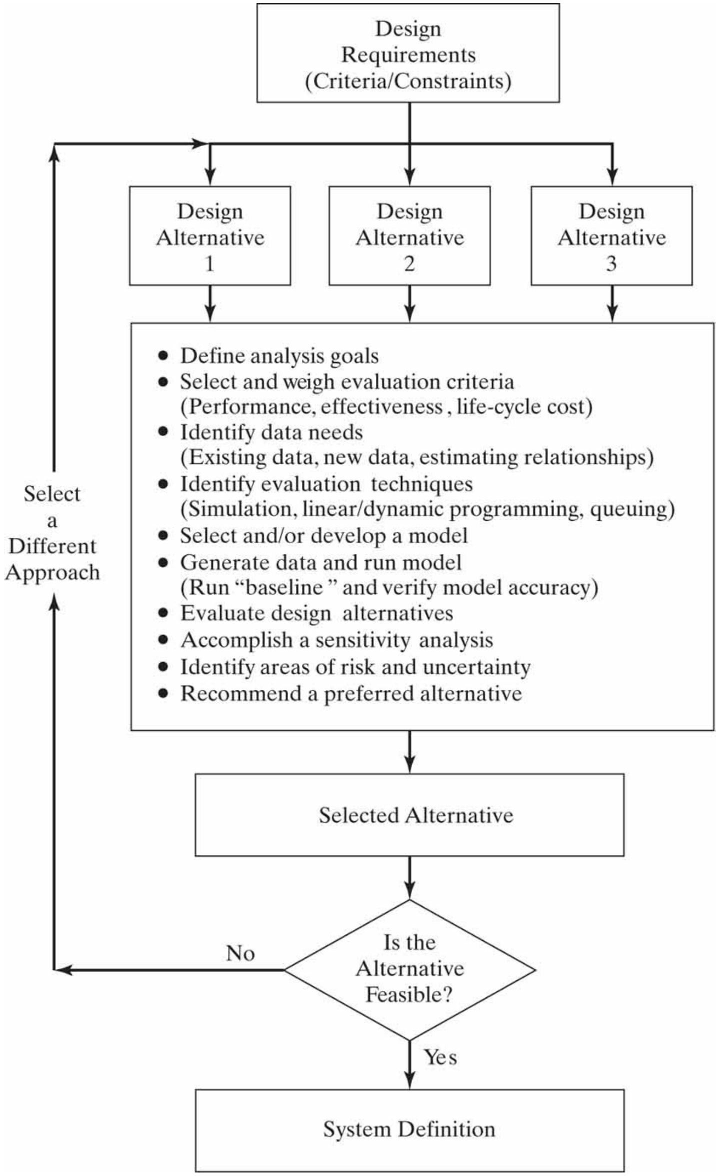


Figure 3.26 Trade-off analysis process.



Design Tools and Aids

- The **successful completion of the design process** depends on the **availability of the appropriate tools and design aids.**
- The application of CAD and CAE tools enables the projection of many different design alternatives throughout the life cycle.
- In particular at the earliest stages, **it is very difficult to visualize a system configuration** (or element thereof)
- In some instances, **the validation of system requirements** can be accomplished through the use **simulation methods** during preliminary system design and detail design and development phases before the introduction of hardware and software , and so on
- Physical **3D scale models** or **mock-ups** are sometimes constructed to provide a realistic simulation of a proposed system configuration: heavy cardboard, wood, metal, or combination of different materials.

Design Tools and Aids

- Some of the uses and values of a mock-up are that they:
  - Provide the designer engineer with the opportunity of experimenting with different facilty layouts, packaging schemes, etc.
  - Provide the reliability-maintainability-human factors engineers with the opportunity to accomplish a more effective review
  - Provide the design engineer with an excellent tool for conveying the final design approach during the review
  - Serve as a marketing tool
  - Can be used in developing fabrication and assembly processes and procedures

- Developing a ***"prototype"*** early in the system design process – This iterative and evolutionary process of software development is referred to as ***rapid prototyping***

Design Data, Information, and Integration

- The methods for documenting design are changing rapidly
- Many advances have been made in the application of computerized methods to data acquisition, storage, and retrieval, the need for some of the more conventional methods of design documentation remains:
    - Design drawings
    - Martials and part lists
    - Analyses and reports
    - Others

Development of Engineering Models

- As ***the system design and development effort progresses***, the basic process evolves from the description of the design in the form of documentation and databases to construction of physical models or mock-up, to the construction of engineering model in the lab or prototype, to the construction of the final product
- The purpose in **proceeding through these steps** is to provide a **solid basis for design evaluation and validation**
- The first two steps in this development:
    - Mock-up
    - Data documentation requirements
- At some point, it maybe appropriate to produce an engineering model (laboratory model) to demonstrate some of the functions

System Prototype Development

- A ***prototype model*** represents the production/construction configuration of a system in all aspects of form except it has not been ***fully "qualified"*** in terms of operational

- It is constructed of ***approved and common component parts*** using standard assembly and test processes, and is of the ***same design configuration*** will ultimately be delivered to the customer

- It is made up of the required prime equipment, operational software, operational facilities, and associated elements, etc.

- ***Areas of of noncompliance*** with the specified requirements are identified and ***corrective is initiated***

Design Review, Evaluation, and Feedback

- The design review and evaluation activity is to evaluate and assess if the design configuration is in compliance with the initially specified quantitative and qualitative requirements such as tracking and measuring TPMs.
- The review process is continuous and includes:
    - Informal ongoing iterative day-to-day process of review and evaluation, and
    - Scheduling formal review at discrete point in time
- **Tracking and controlling to TPMs**
    - 5 keys have been selected in Fig. 5.9 to illustrate the tracking of TPMs
    - For a large systems, there may be several distinct TPM requirements that must be met and there should be priorities established to indicate the relative degrees of importance Fig. 5.10

Figure 5.9 Parameter measurement and evaluation at design review ("tracking").

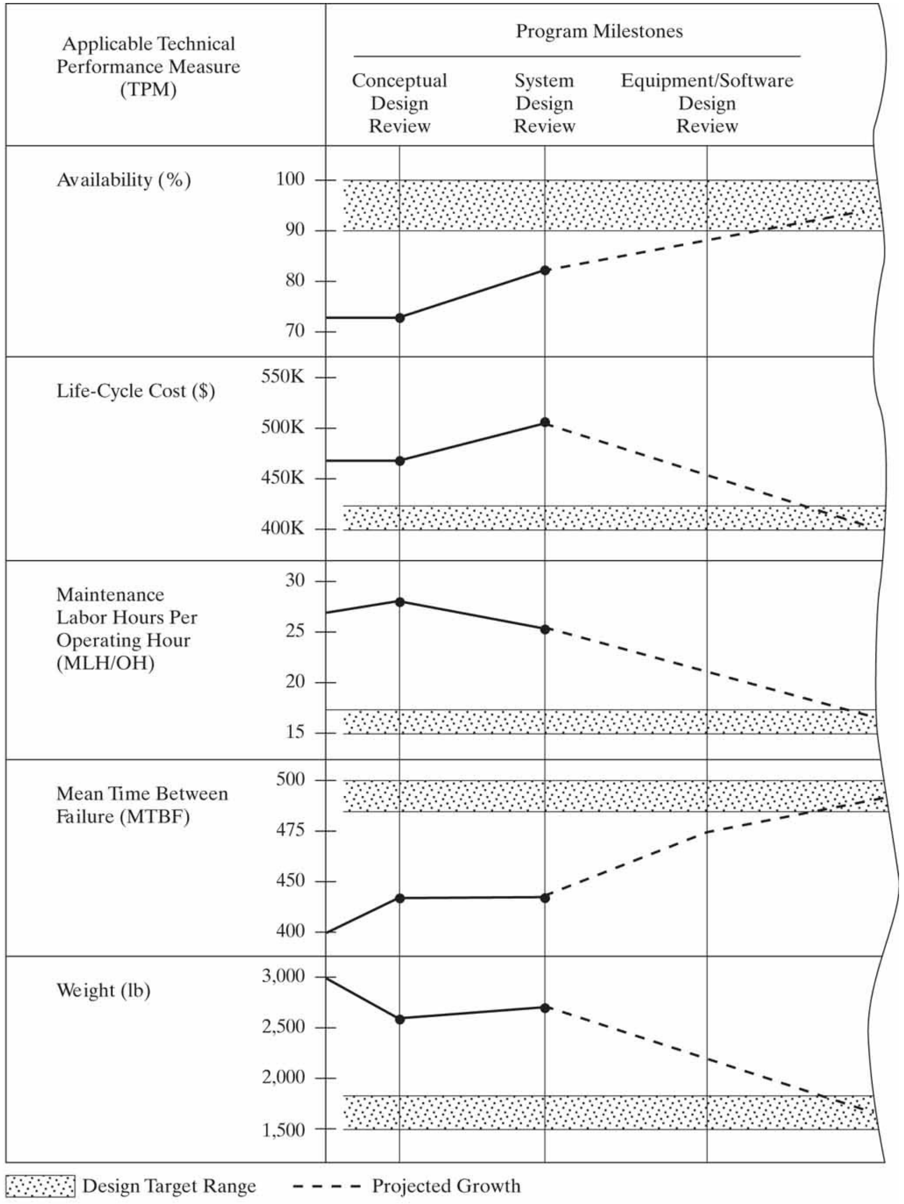


Figure 5.10 The relationship between TPMs and responsible design disciplines (refer to Figure 3.17). H = interest; M = medium interest; and L = low interest.

Technical Performance Measures (TPMs) \ Engineering Design Functions	Aeronautical Engineering	Components Engineering	Cost Engineering	Electrical Engineering	Human Factors Engineering	Logistics Engineering	Maintainability Engineering	Manufacturing Engineering	Materials Engineering	Mechanical Engineering	Reliability Engineering	Structural Engineering	Systems Engineering
Availability (90%)	H	L	L	M	M	H	M	L	M	M	M	M	H
Diagnostics (95%)	L	M	L	H	L	M	H	M	M	H	M	L	M
Interchangeability (99%)	M	H	M	H	M	H	H	H	M	H	H	M	M
Life cycle cost ($350K, unit)	M	M	H	M	M	H	H	L	M	M	H	M	H
$\overline{M}$ct (30 min)	L	L	L	M	M	H	H	M	M	M	M	M	M
MDT (24 hr)	L	M	M	L	L	H	M	M	L	L	M	L	H
MLH/OH (15)	L	L	M	L	M	M	H	L	L	L	M	L	H
MTBF (300 hr)	L	H	L	M	L	L	M	H	H	M	H	M	M
MTBM (250 hr)	L	L	L	L	L	M	H	L	L	L	M	L	H
Personnel skill levels	M	L	M	M	H	M	H	L	L	L	L	L	H
Size (150 ft by 75 ft)	H	H	M	M	M	M	M	H	H	H	M	H	M
Speed (450 mph)	H	L	L	L	L	L	L	L	L	L	L	M	H
System effectiveness (80%)	M	L	L	M	L	M	M	L	L	M	M	M	H
Weight (150K lb)	H	H	M	M	M	M	M	H	H	H	L	H	M

Assignment 5

Based on your selected team project:

1) The conceptual design report,
2) The preliminary system design report
3) Detailed design and development report – identify your components, and units, etc.
4) Ensure that the TPMs are in compliances with all the subsystems and components, and tracking is in place