Chapter 4

Preliminary System Design

Preliminary System Design

- The **conceptual design process** presented in Chapter 3 leads to the selection of a tentatively preferred: ***Conceptual System Design Architecture or Configuration***

- Top-level requirements, as above, enable early design evolution in the ***Preliminary System Design phase***

- An **essential purpose** of the preliminary design is to **demonstrate** that the selected system concept will conform to performance and design specifications

- It can be **produced and/or constructed** with **available methods**

- And the **established cost** and **schedule** constraints can be **met**

Preliminary System Design

This chapter addresses the following steps:

- Developing design requirements for subsystems and major system elements from system-level requirements
- Preparing ***development, product, process***, and ***materials specifications*** applicable to subsystems
- Accomplishing ***functional analysis*** and ***allocation*** <u>**to and below the subsystem level**</u>
- Establishing detailed design requirements and ***developing plans*** for their <u>handoff</u> to ***engineering domain specialists***
- Identifying and utilizing appropriate ***engineering design tools*** and ***technologies***
- Conducting ***trade-off studies*** to <u>achieve design and operational effectiveness</u>
- Conducting ***design review*** on <u>regular basis</u> or predetermined points in time

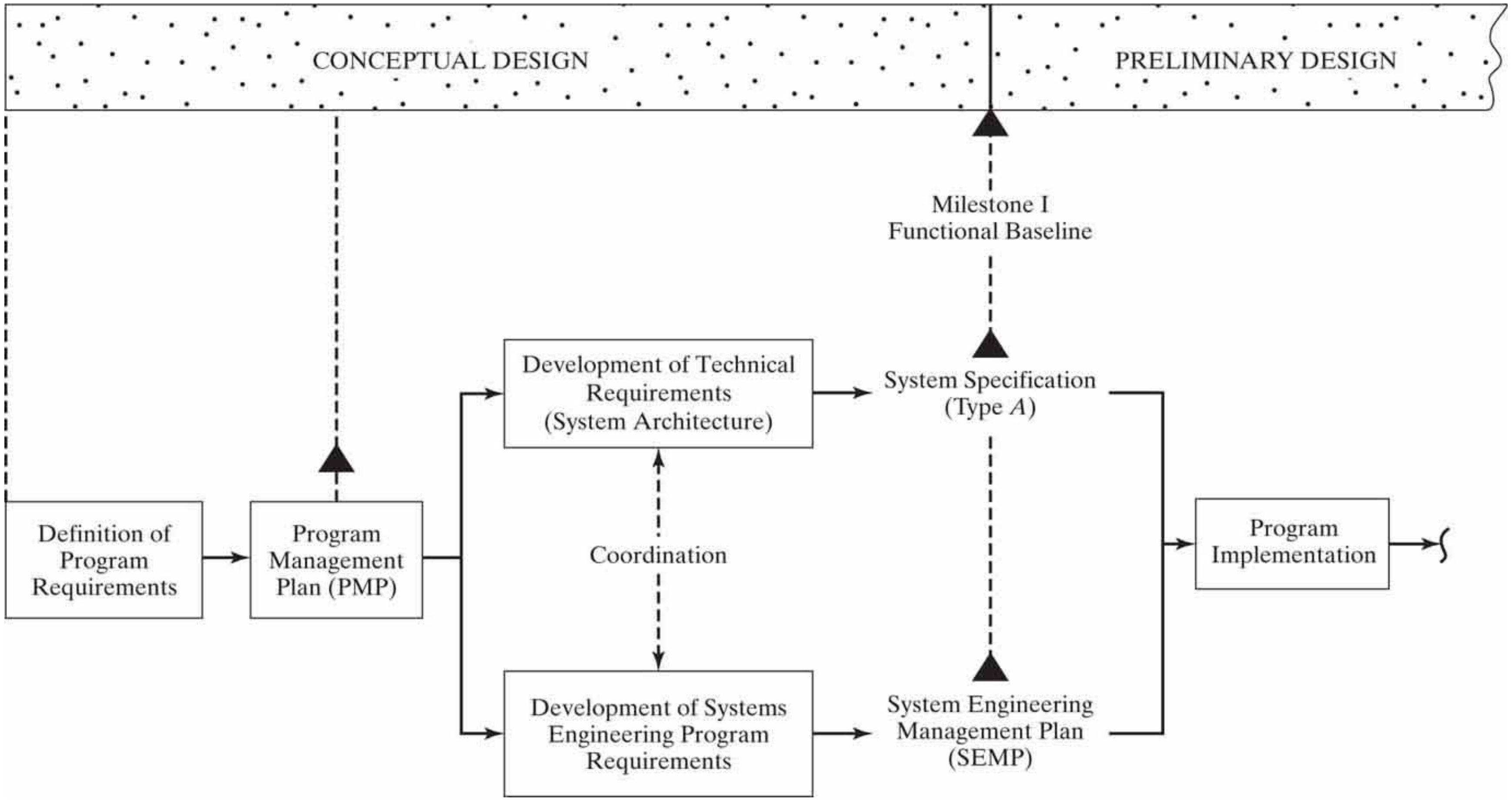
Preliminary Design Requirements

- ***Preliminary design requirements*** evolve from System design requirements
- System design requirements are determined through:
    - *System Operational Requirements*
    - *Maintenance and support concept*
    - *Identification and prioritization of TPMs*

Note:

1. These requirements are documented through the preparation of the system specification (Type A)
2. These requirements become the criteria by which preliminary design alternatives are judged

Figure 3.1 Early system advanced planning and architecting.



Preliminary Design Requirements

- The ***whats*** initiating conceptual design produce ***hows*** from the conceptual design evaluation effort applied to feasibility conceptual design concepts

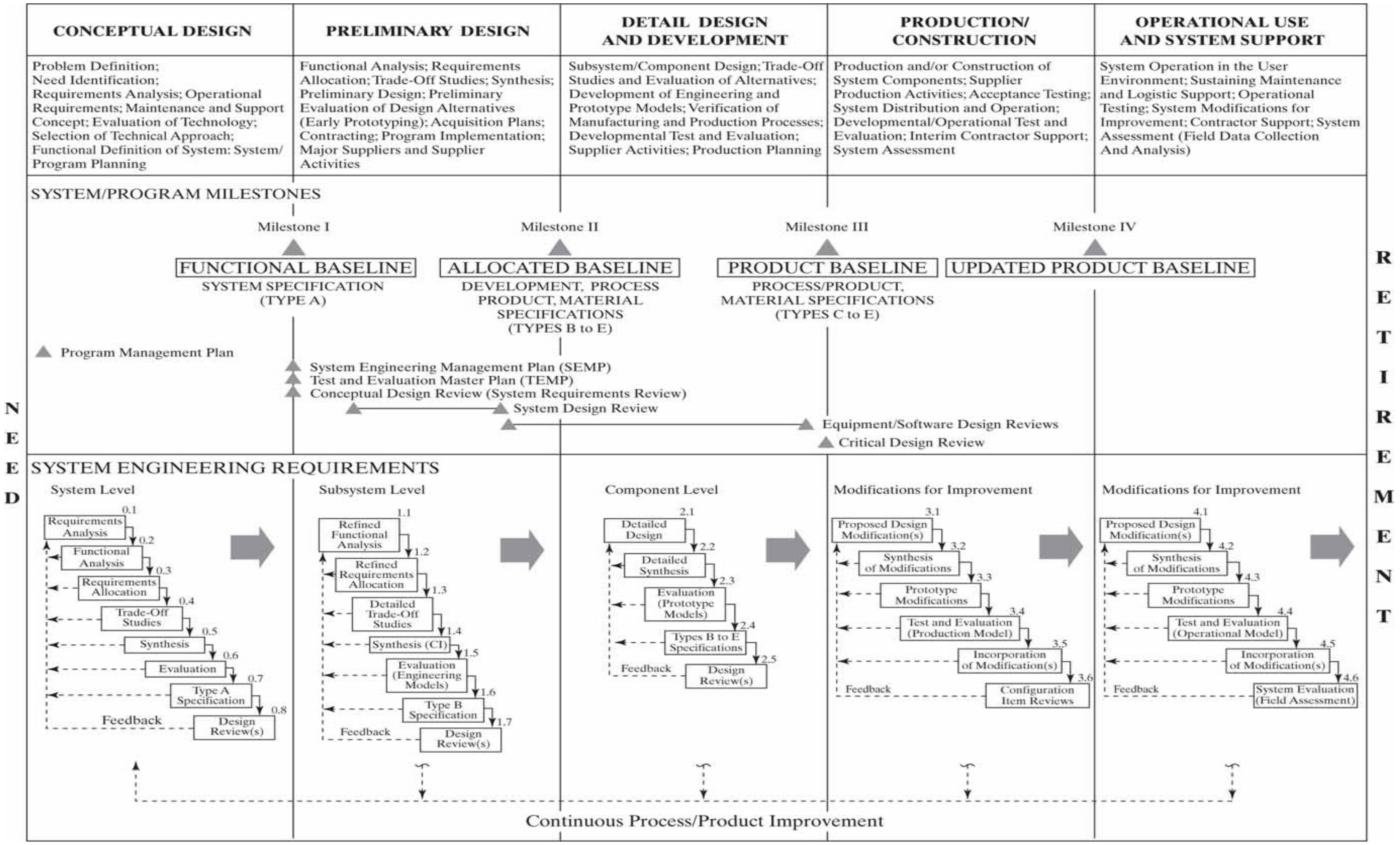
- Next, the ***hows*** are taken into preliminary design through the means of allocated requirements. They becomes the ***whats*** and drive the preliminary design to address ***hows*** at the lower levels.

- This is a **cascading process** following pattern exhibited in Fig. 2.4

- **Requirements** for the design of subsystems and the major elements of the system are *defined through an extension of functional analysis and allocations, trade-off studies and so on – Iterative process*

- These lower-level requirements are **documented** through <u>**Development, Product, Process, and Material Specifications**</u>

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



System Specification

- Throughout the conceptual system design phase (commencing with the needs analysis), one of the major objectives is to develop and define ***the specific "design-to" requirements for the system as an entity***
- The activities results described in ***3.3 – 3.8*** are ***combined, integrated, and included in a system specification (type A)***
- This ***specification constitutes the top "technical-requirements" documents*** that provides overall guidance for system design from the beginning
- This top-level specifications provides the baseline for the development of all lower-level specifications to include:
  - ***Development (Type B)***
  - ***Product (Type C)***
  - ***Process (Type D), and***
  - ***Materials (Type E)***

Figure 3.27 Type *A* system specification format (example).

System Specification

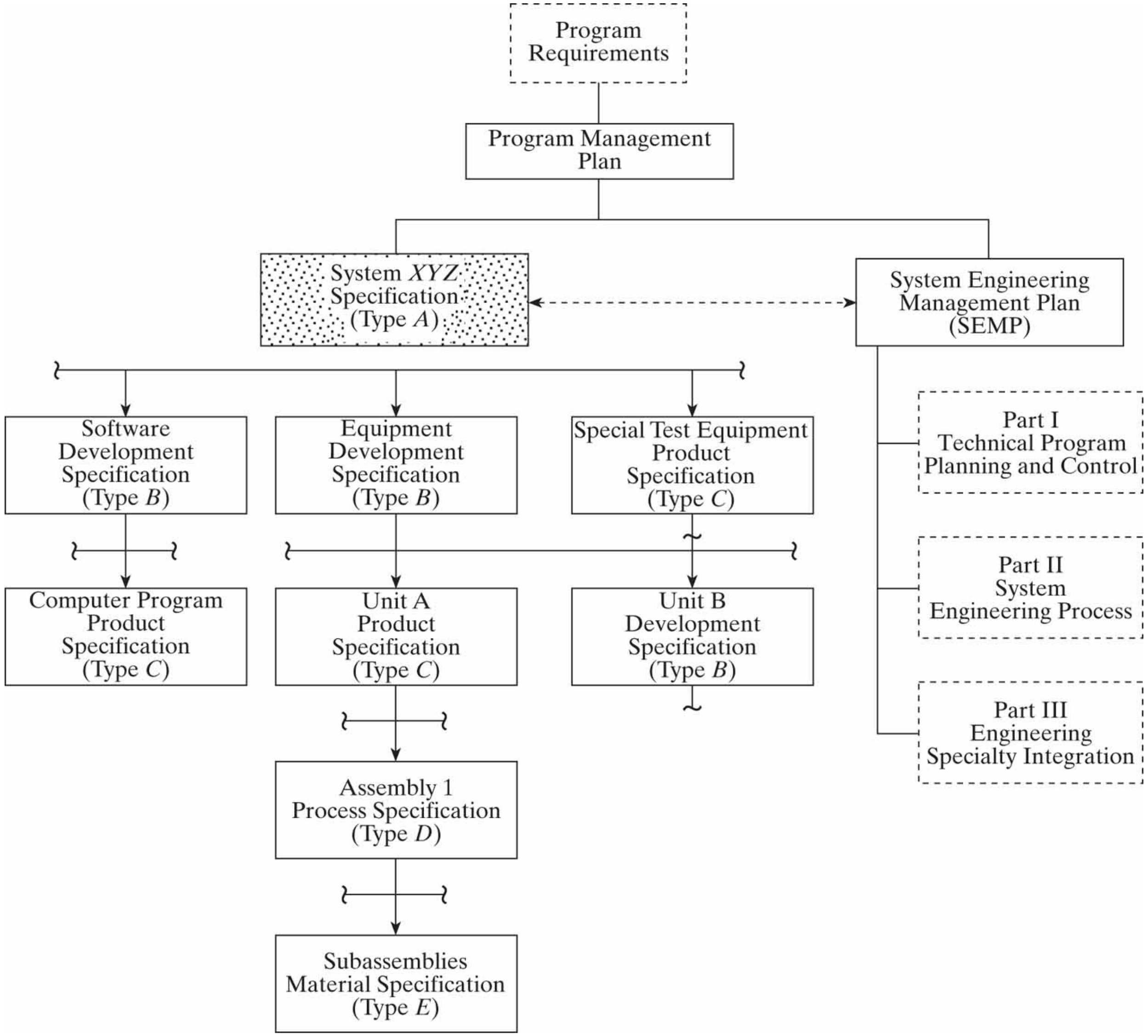
1.0 Scope
2.0 Applicable Documents
3.0 Requirements
- 3.1 System Definition
  - 3.1.1 General Description
  - 3.1.2 Operational Requirements (Need, Mission, Use Profile, Distribution, Life Cycle)
  - 3.1.3 Maintenance Concept
  - 3.1.4 Functional Analysis and System Definition
  - 3.1.5 Allocation of Requirements
  - 3.1.6 Functional Interfaces and Criteria
- 3.2 System Characteristics
  - 3.2.1 Performance Characteristics
  - 3.2.2 Physical Characteristics
  - 3.2.3 Effectiveness Requirements
  - 3.2.4 Reliability
  - 3.2.5 Maintainability
  - 3.2.6 Usability (Human Factors)
  - 3.2.7 Supportability
  - 3.2.8 Transportability/Mobility
  - 3.2.9 Flexibility
  - 3.2.10 Sustainability
  - 3.2.11 Security
- 3.3 Design and Construction
  - 3.3.1 CAD/CAM Requirements
  - 3.3.2 Materials, Processes, and Parts
  - 3.3.3 Mounting and Labeling
  - 3.3.4 Electromagnetic Radiation
  - 3.3.5 Safety
  - 3.3.6 Interchangeability
  - 3.3.7 Workmanship
  - 3.3.8 Testability
  - 3.3.9 Economic Feasibility
- 3.4 Documentation/Data
- 3.5 Logistics
  - 3.5.1 Maintenance Requirements
  - 3.5.2 Supply Support
  - 3.5.3 Test and Support Equipment
  - 3.5.4 Personnel and Training
  - 3.5.5 Facilities and Equipment
  - 3.5.6 Packaging, Handling, Storage, and Transportation
  - 3.5.7 Computer Resources (Software)
  - 3.5.8 Technical Data/Information
  - 3.5.9 Customer Services
- 3.6 Producibility
- 3.7 Disposability
- 3.8 Affordability

4.0 Test and Evaluation
5.0 Quality Assurance Provisions
6.0 Distribution and Customer Service
7.0 Retirement and Material Recycling/Disposal

Development, Product, Process, and Material Specifications

- The **<u>technical</u>** requirements for the system and its elements are documented through a series of specification as in Fig. 2.4
- This series commences with the preparation of the ***system specifications (Type A)*** prepared in the Conceptual Design phase
- In turn, this leads to one or more subordinate specifications and/or standard covering applicable subsystems etc.
- Other supplemental ANSI (American National Standards Institute), EIA (Electronic Industries Alliance), etc. that are required to support the basic program-related specifications

Figure 4.1 Program documentation tree.



Development, Product, Process, and Material Specifications

- The development of a ***specification tree*** is <u>recommended</u> for each program Fig 4.1
- Showing hierarchical relationship in terms of which specifications has ***“preference”*** in the event of conflict. Make sure:
  - Traceability of requirements from the top down
  - Development Specifications(Type B), Product Specifications (Type C), and so on <u>**must include the appropriate TPM requirements**</u> that will support and overall-all requirements
  - ***Traceability requirements***, through a specification tree, is particularly <u>**important in view of current trends**</u> pertaining to increasing globalization, greater outsourcing, and the increasing utilization of external suppliers and so on, where variations often occur in implementation different practices and standards

Development, Product, Process, and Material Specifications

- **System specification (Type A):** Includes the technical, performance, operational and support for the system as an entity – The appropriate TPMs requirements, Functional description, Design requirements, and allocation requirements

- **Development specification (Type B):** Includes the technical requirements (qualitative, and quantitative) for any new item below the system level where research, design, and development are needed. This may cover an item of equipment, software, facility, data, etc.

- **Product specification (Type C):** Includes the technical requirements (qualitative and quantitative) for any item below the system level that is currently in inventory and can be procured (off the shelf) and it may cover any commercial off the shelf (COTS) equipment, software module, component, etc.

- **Process specification (Type D):):** Includes the technical requirements (qualitative and quantitative) associated with a process and/or a service performed on any element of the system, e.g., manufacturing process, a logistics process (material handling, transportation)

- **Materials specification (Type E):** Includes the technical requirements that pertain to raw materials (metals, sand, etc), liquids (chemical compounds)

Development, Product, Process, and Material Specifications

Note:

Each **applicable specification** must be complete, and written in **performance related terms** and must describe the appropriate design requirements in terms of the **whats**.

That is, the function(s) that the item in question must perform.

Functional Analysis and Allocation (Subsystem)

- The next step is to extend the functional analysis from the system level down to the **subsystem and below**

- The **breakdown** in developing FFBDs from system level to the second level, third level, and so on. The depth of such an analysis varies depending on the degree of visibility desired (<u>new design, or to the level at which the designer wishes to establish some specific design-to requirements an input</u>)

Functional Analysis and Allocation (Subsystem)

The Functional Analysis Process

- There are a variety of illustrations showing a breakdown of functions into subfunctions and
- Ultimately describing major subsystems Fig 3.23
- Same approach can be applied in defining other subsystems

- Development of **operational FFBDs** can lead to the development of the operational and maintenance FFBDs, Fig 3.21
- Given completion of the operational and maintenance FFBDs that reflect the **<u>whats</u>**, one must determine the **<u>hows</u>**
- ***How will each function be accomplished?***
- This is realized by evaluating each individual block of an FFBD
  - Defining the necessary ***inputs*** and expected ***outputs***
  - Describing the ***external controls*** and ***constraints***, and determining the ***mechanisms*** or the physical resources required for accomplishing the function (equipment, software, people, etc) Fig 4.2

Figure 3.23 Progression from the “need” to the functional analysis.

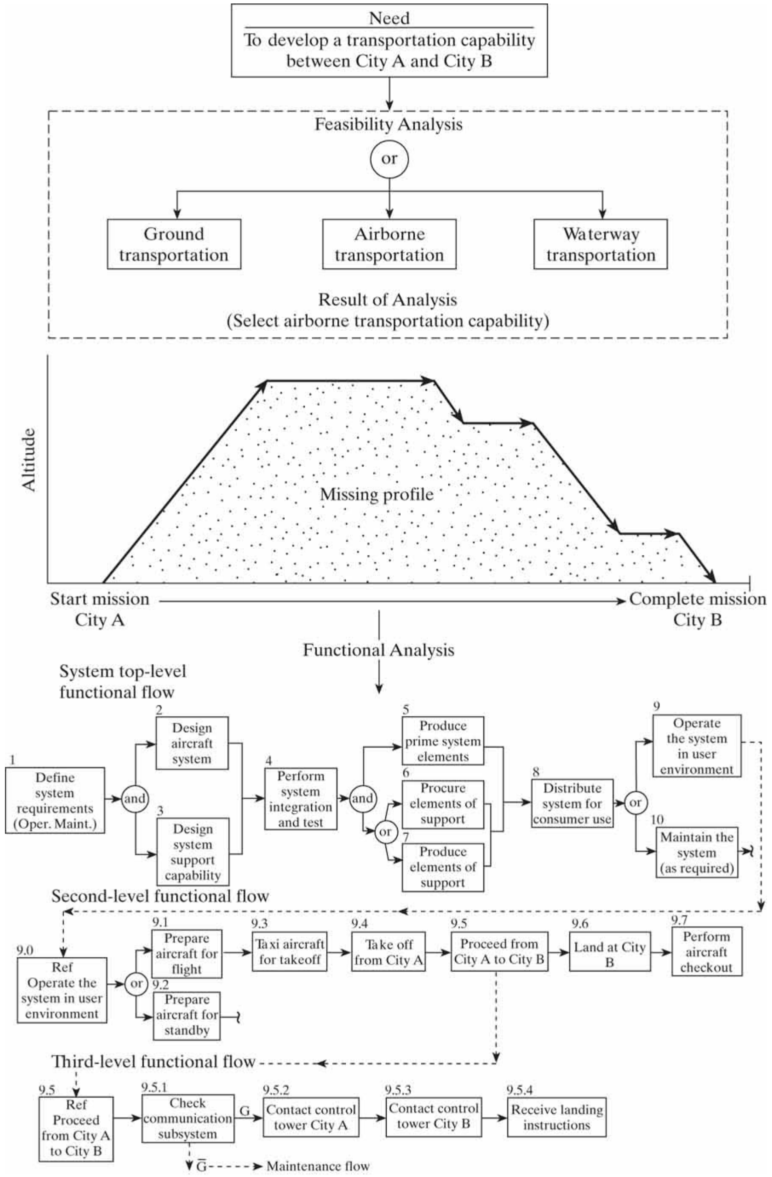


Figure 3.21 Functional block diagram expansion (partial).

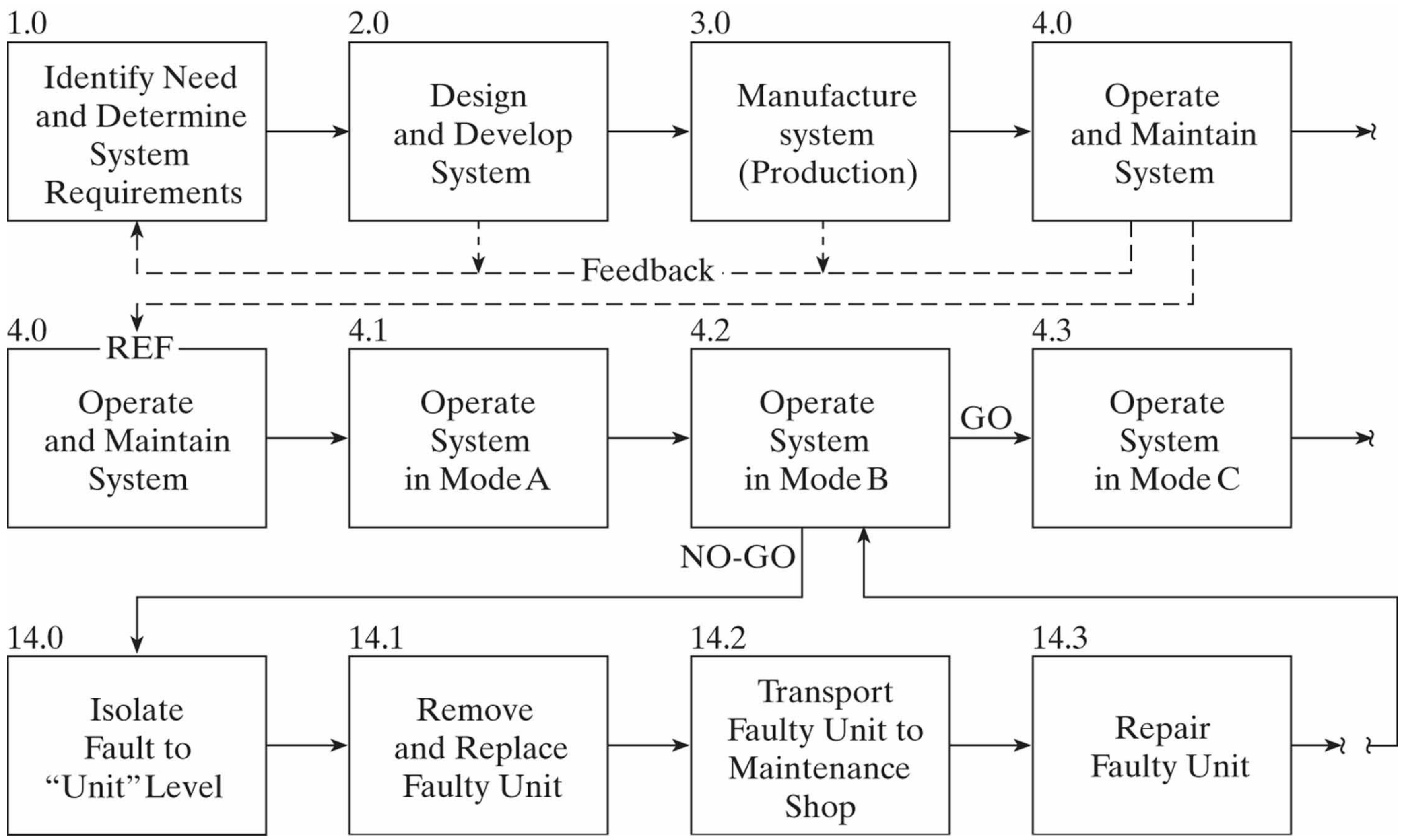
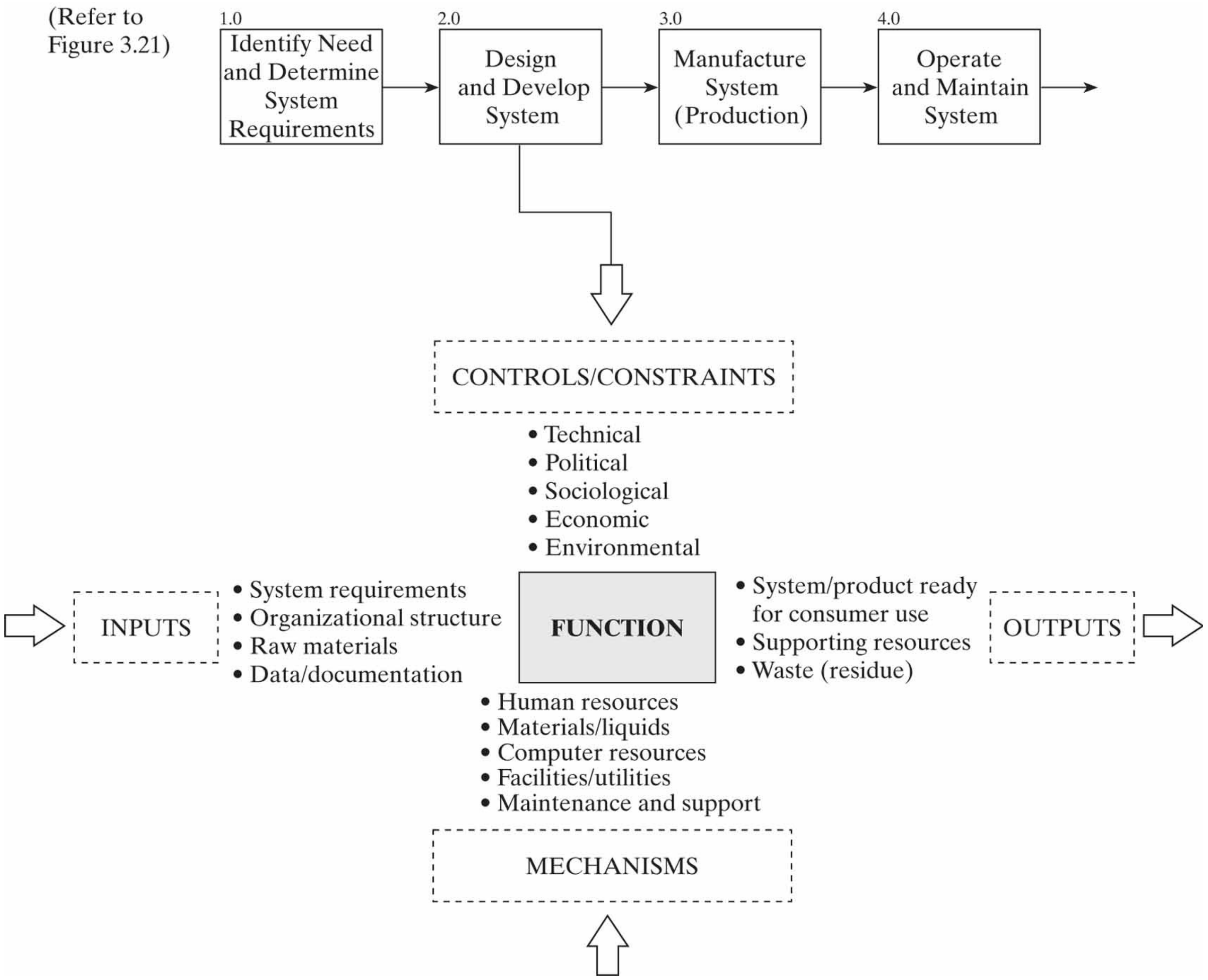


Figure 4.2 Identification of resource requirements (mechanisms).

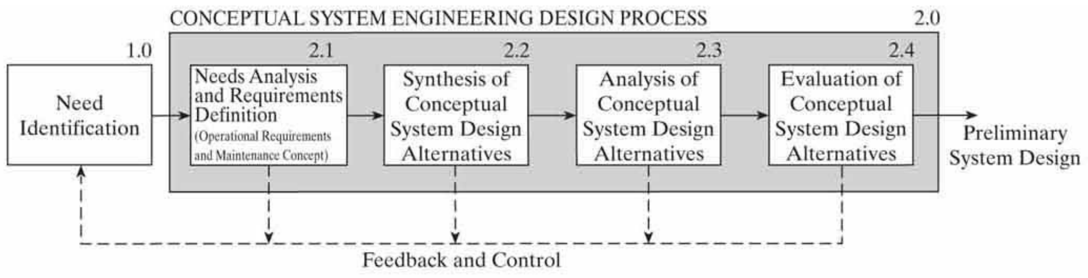


Functional Analysis and Allocation (Subsystem)

The Functional Analysis Process

- A ***documentation format***, similar to Fig 4.3 (or something similar), should be used
- In the figure, the ***function*** pertaining to system design and development are identified along with ***required inputs, expected outputs, and anticipated resources requirements***
- This particular example is ***"qualitative"*** by nature
- There could be many functions where specific metrics (i.e., TPMs) can be applied in the form of design-to ***"constraints"***
- Fig 3.23 functional requirement at system level: *"Operate the system in the user environment"* Block 9.0 – Assuming TPM for *operational availability (Ao)* of 0.985
- Fig. 4.3 is to promote a **disciplined approach** in accomplishing a functional analysis

Figure 4.3 Documentation format reflecting functions, input–output requirements, and resource requirements (partial).



Activity Number	Activity Description	Required Inputs	Expected Outputs	Resource Requirements
1.0	Need identification	Customer surveys; marketing inputs; shipping and servicing department logs; market niche studies; competitive product research.	A specific qualitative and quantitative needs statement responding to a current deficiency. Care must be taken to state this need in functional terms.	Benchmarking; statistical analyses of data (i.e., data collected as a result of surveys and consolidated from shipping and servicing logs, etc.).
2.1	Needs analysis and requirements definitions	A specific qualitative and quantitative needs statement expressed in functional terms.	Qualitative and quantitative factors pertaining to system performance levels, geographical distribution of products, expected use profiles, user/consumer environment; operational life cycle, effectiveness requirements, the levels of maintenance and support, consideration of the applicable elements of logistic support, the support environment, and so on.	Quality function deployment (QFD), input–output matrix, checklists; value engineering; statistical data analysis; trend analysis; matrix analysis; parametric analysis; various categories of analytical models and tools for simulation studies, trade-offs, etc.
2.2	Synthesis of conceptual system design alternatives	Results from needs analysis and requirements definition process; technology research studies; supplier information.	Identification and description of candidate conceptual system design alternatives and technology applications.	Pugh's concept generation approach; brainstorming; analogy; checklists.
2.3	Analysis of conceptual system design alternatives	Candidate conceptual solutions and technologies; results from the needs analysis and requirements definition process.	Approximation of the "goodness" of each feasible conceptual solution relative to the pertinent parameters, both direct and indirect. This goodness could be expressed as a numeric rating, probabilistic measure, or fuzzy measure.	Indirect system experimentation (e.g., mathematical modeling and simulation); parametric analyses; risk analyses.
2.4	Evaluation of conceptual system design alternatives	Results from the analysis task in the form of a set of feasible conceptual system design alternatives.	A single or short-listed set of preferred conceptual system designs. Further, a "feel" for how much better the preferred approach(es) is relative to all other feasible alternatives.	Design-dependent parameter approach; generation of hybrid numbers to represent candidate solution "goodness"; conceptual system design evaluation display.

Functional Analysis and Allocation (Subsystem)

Requirement Allocation

- **Lower-level elements** of the system are defined through the functional analysis and subsequently by **partitioning (or grouping)** <u>similar functions into logical subdivision, identifying major subsystems, units, modules and so forth</u> Fig. 3.25

- Fig 4.5 presents an overview of this process **evolving** from the definition of system XYZ to the **packaging of the system into three units: Units A, B, and C.**
- Given the packaging concept shown in Fig 4.5, **determine the "design-to" requirements** for each of the three units
  - This is accomplished through the **process of allocation**
  - In the development of the design goals at unit level, **priorities** are established based on TPMs for the system Fig 3.17
  - Both qualitative and quantitative design requirements are determined
  - Such requirements lead to the incorporation of the appropriate design characteristics Fig 2.8

Figure 4.5 The functional packaging of the system into major elements.

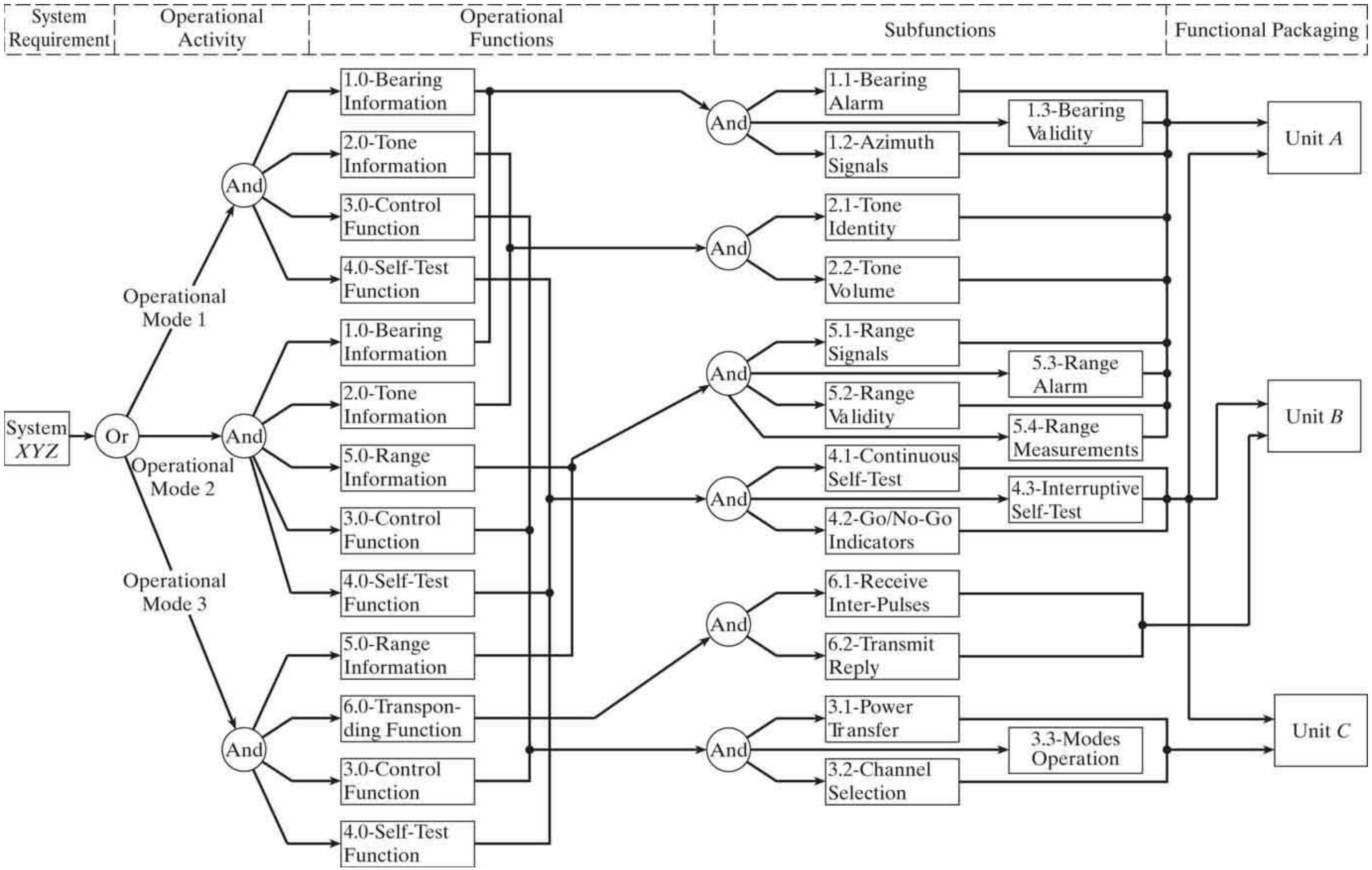
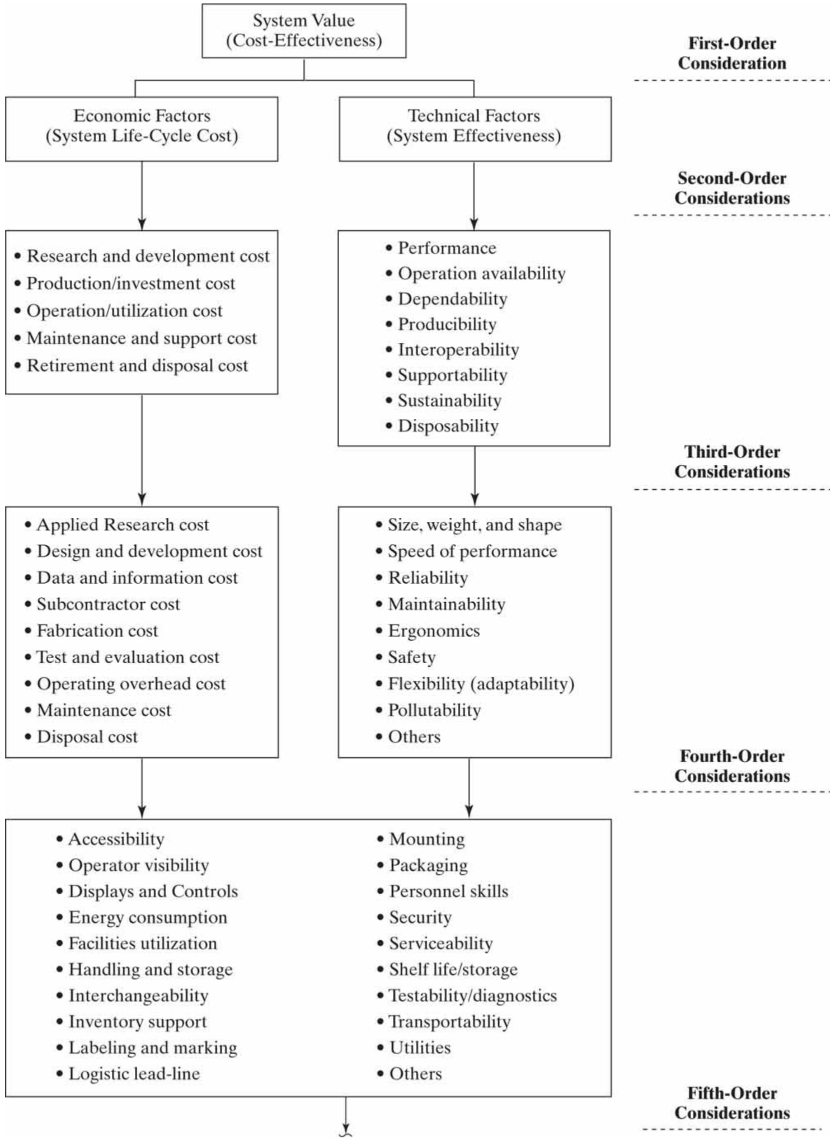


Figure 3.17 Prioritization of technical performance measures (TPMs).

Technical Performance Measure	Quantitative Requirement ("Metric")	Current "Benchmark" (Competing Systems)	Relative Importance (Customer Desires) (%)
Process time (days)	30 days (maximum)	45 days (system M)	10
Velocity (mph)	100 mph (minimum)	115 mph (system B)	32
Availability (operational)	98.5% (minimum)	98.9% (system H)	21
Size (feet)	10 feet long 6 feet wide 4 feet high (maximum)	9 feet long 8 feet wide 4 feet high (system M)	17
Human factors	Less than 1% error rate per year	2% per year (system B)	5
Weight (pounds)	600 pounds (maximum)	650 pounds (system H)	6
Maintainability (MTBM)	300 miles (minimum)	275 miles (system H)	9
			100

Figure 2.8 A hierarchy of system design considerations.

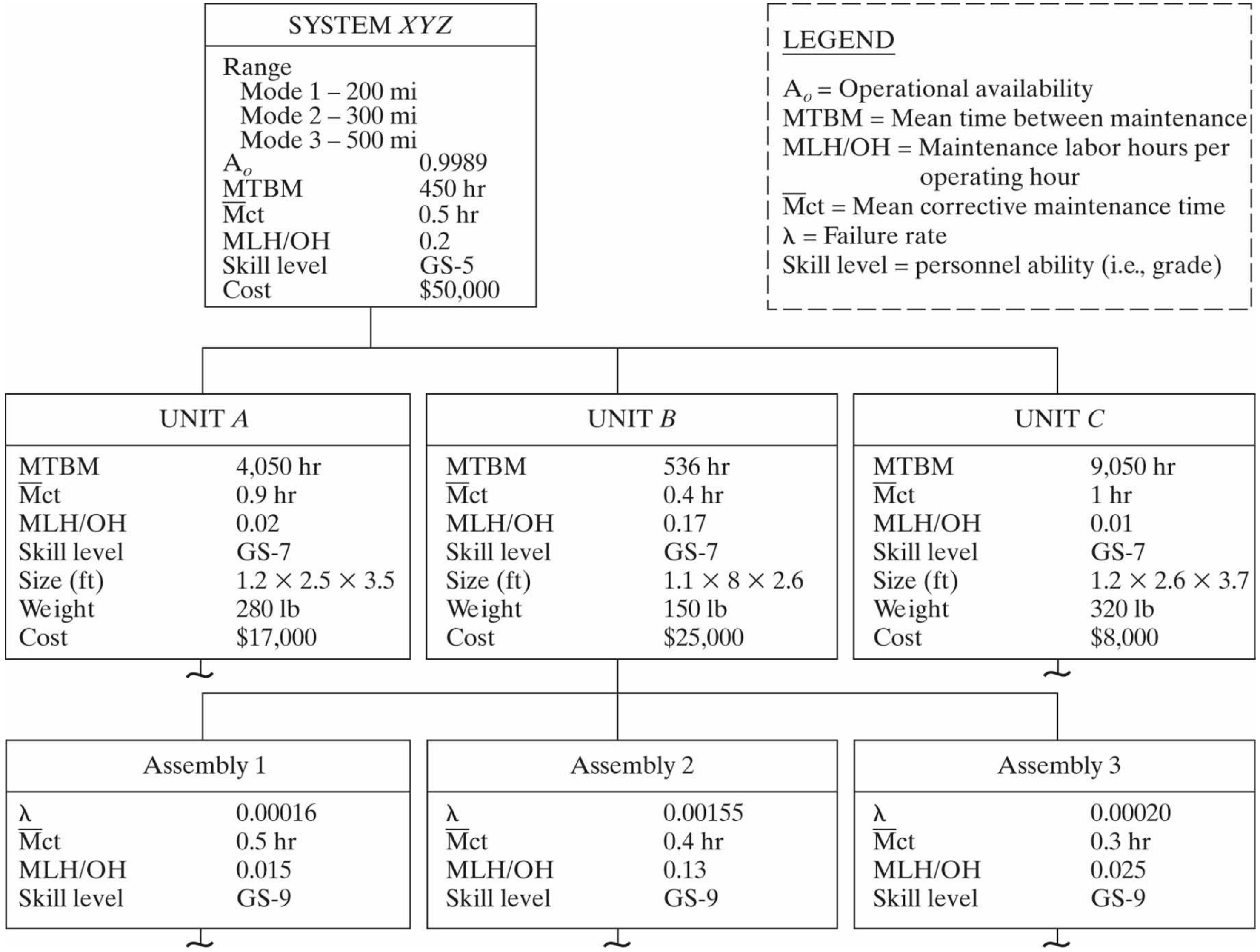


Functional Analysis and Allocation (Subsystem)

Requirement Allocation

- Example: Fig 4.6 presents a result from the allocation process described
- System-level TPMs are identified along with the design-to metrics for each of the three units, as well as requirements for Assemblies 1, 2, and 3 of unit B
- The requirements at the system level have been allocated **downward**
- The requirements established at the unit level, when combined, must be **compatible** with the higher-level requirements (There must be trade-offs conducted comprehensively at unit level to achieve the balance of requirements overall)
- Fig 4.6 emphasizes the **process** and its **importance early in system design**
- Not all metrics are shown, only reliability, maintainability, availability, …

Figure 4.6 System *XYZ* requirements allocation.



Assignment 4

Based on your selected team project:

1) Develop operational functional flow block diagrams (FFBDs) to the third level. Select one of the functional blocks and develop maintenance flows to the second level. Show how the maintenance functional flow diagram evolve from the operational flows. Use your project
2) Describe how specific resource requirements (hardware, software, people,..) are derived from the functional analysis. Example form the project
3) Describe the steps involved in transitioning from the functional analysis to a ”packaging scheme” for the system. Use your project.