# Chapter 3

## Conceptual System Design

# Conceptual System Design

- ***Conceptual Design*** is the first and most important phase of the system design and development process
- Early and high-level life-cycle activity to:
  - Establish,
  - Commit
  - Predetermine the function, form, cost and development schedule of the desired systems and its products
- **Major purpose of the Conceptual Design**: Selection of path forward for the design and development of a preferred system architecture that is **responsive** to the identified customer needs
- **Critical Initial Steps**:
  - Systems engineering takes the lead in the **solicitation of system requirements** from the beginning
  - Establishing this foundation early
  - Early Planning and evaluation of alternative technological approaches

# Conceptual System Design

- **Systems Engineering Process Steps**:
  - **Define the problem, or the current deficiency**, which then leads to the identification of a need for a system that will ultimately provide a solution
  - Accomplishing **system planning and architecting** in response to the customer needs
  - Developing **system operational requirements** describing the functions that the system must perform
  - Proposing a maintenance concept for the sustaining support of the system throughout its planned life cycle
  - Identifying and prioritizing TPMs and related criteria for design
  - Accomplishing a system-level functional analysis and allocating requirements to various subsystems and components
  - Performing systems analysis and producing trade-off studies
  - Developing system specification, and
  - Conducting a conceptual design review

# Conceptual System Design

- **Chapter 3's Objectives**:
    - Problem Definition and Need Identification
    - System Planning and Architecting
    - System Design and Feasibility Analysis
    - System Operational Requirements
    - System Maintenance and Support
    - Technical Performance Measures TPMs
    - Functional Analysis and Allocation
    - System Trade-Off Analysis
    - System Specification
    - Conceptual Review

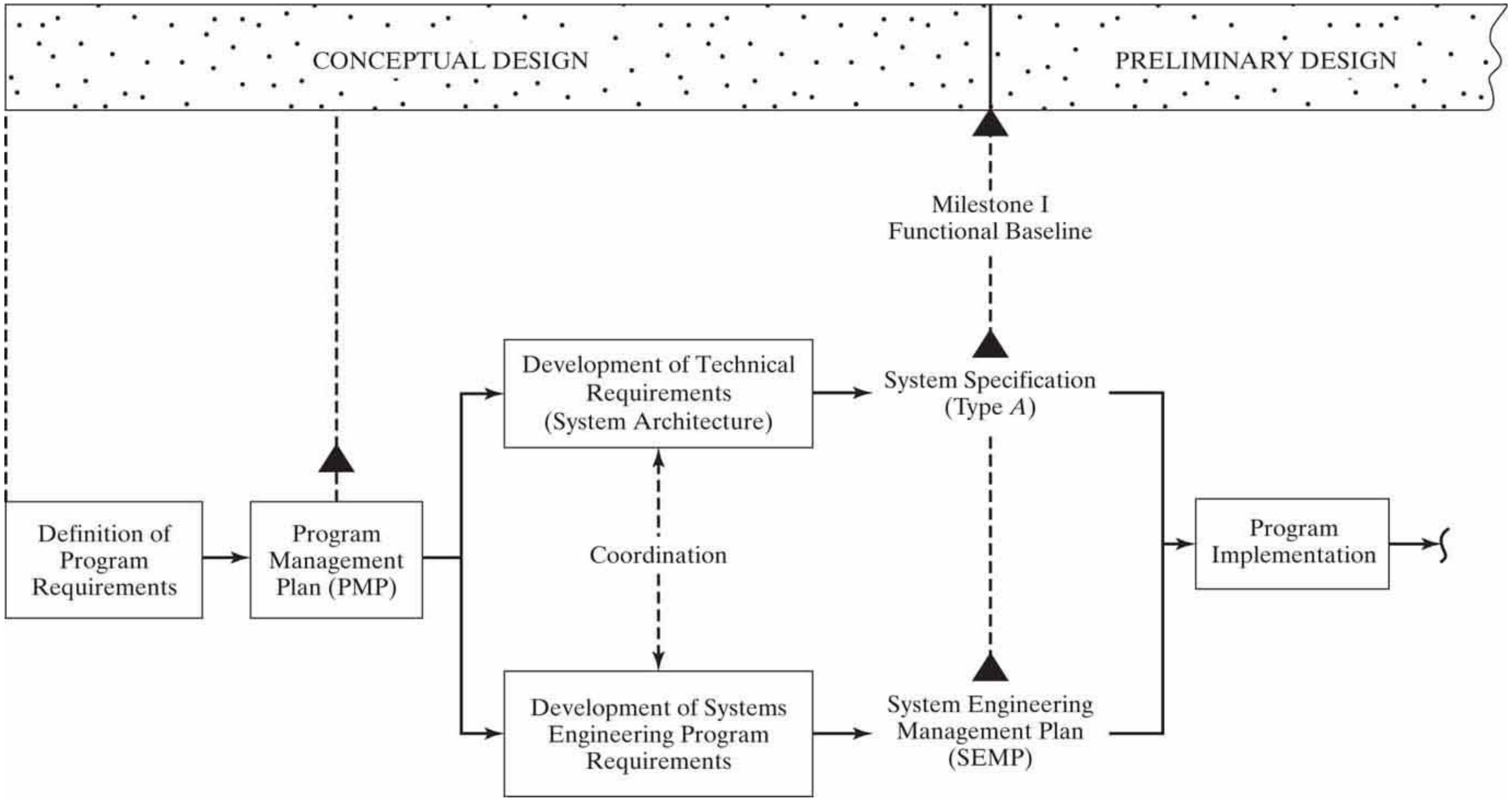
# Problem Definition and Need Identification

- Defining the problem is often the most difficult part of the process
  - The number of false starts and the resulting cost commitment can be significant unless a good foundation is laid from beginning
- The systems engineering process generally commences with the identification of a “want” based on some real deficiency
- Important to commence by
  - First defining the “Problem” and then
  - Defining the need for a specific system capability that is responsive
- Identifying the problem and the needs analysis in a satisfactory manner can be best be realized through a team approach involving the customer, users, prime contractor, major suppliers, etc

# System Planning and Architecting

- The **program requirements** initiate an advanced system planning activity and the development of a **program management plan (PMP)**
- PMP guides (Fig. 3.1) the development of requirement for implementation of a systems engineering program and the preparation of a **system engineering management plan (SEMP)** or **system engineering plan (SEP)**
- The **technical requirements** for the system are <u>**simultaneously**</u> determined
  - Involves development of a system-level architecture (function first and physical later) to include system operational requirements, functional architecture, alternative technical concepts, etc as in (Fig. 3.2)
  - The results lead to the preparation of the **system specification (Type A)**
  - The preparation of the SEMP and the system specification be **accomplished concurrently – <u>docs need talk to each other</u>**

## **Figure 3.1** Early system advanced planning and architecting.

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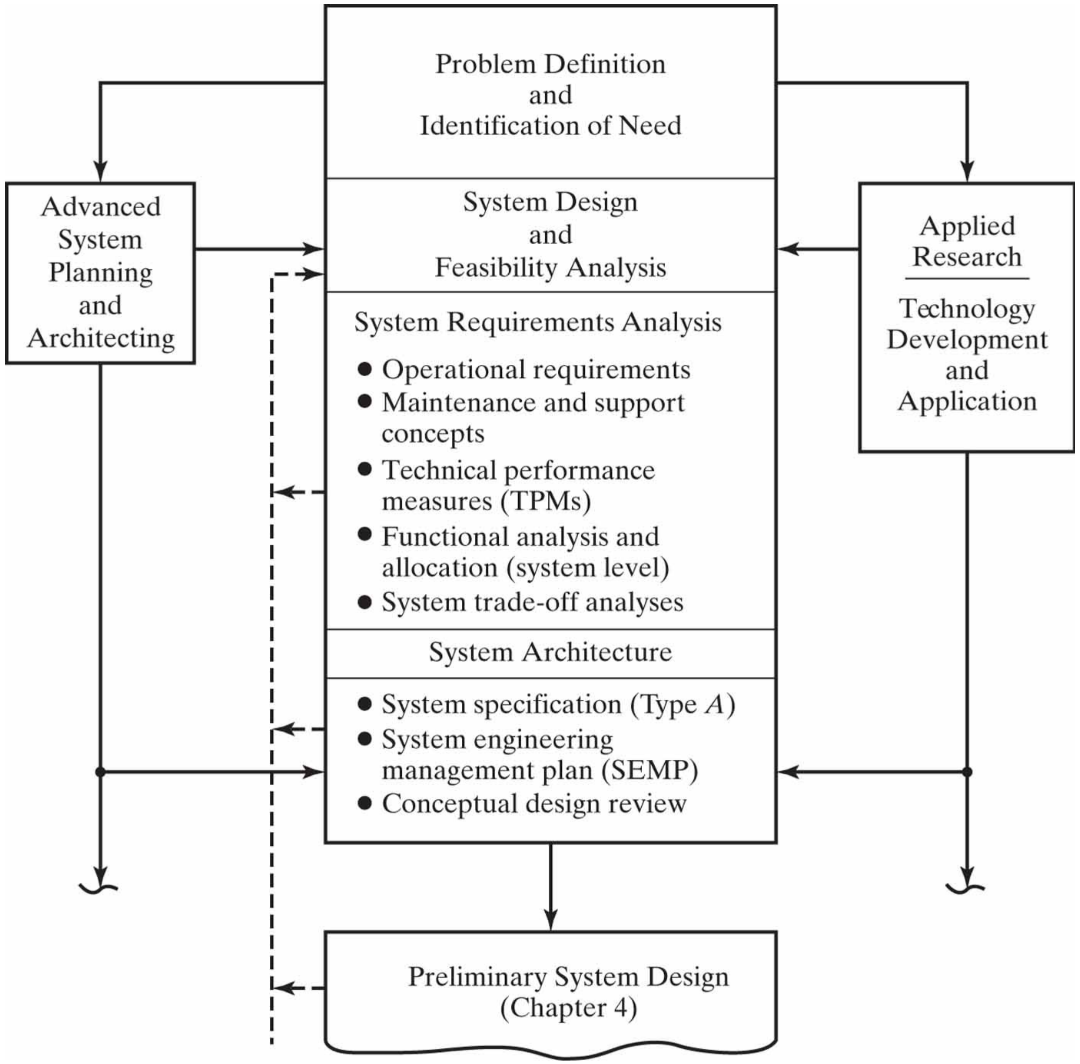
# System Planning and Architecting

- Fig. 3.1 and 3.2 are directly with the activities and milestones in Fig. 2.4
- The system specification (Type A) contains the highest-level architecture and forms the basis for the preparation of all the lower-level specifications in a **top-down manner**
    - *Development (Type B)*
    - *Product (Type C)*
    - *Process (Type D)*
    - *Materials (Type E)*
- Note: They are described further in Section 3.9
- The SEMP is addressed in details in Section 18.2

**Figure 3.2** Major steps in the system requirements definition process.

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# System Design and Feasibility Analysis

- Having justified the need for a new system, it is necessary to:

  - Identify various system-level design approaches or alternatives
  - Evaluate the feasible approaches to find the most desirable in terms of:
    - Performance
    - Effectiveness
    - Maintenance
    - Sustaining support
    - Life-cycle economic criteria
  - Narrow down to those alternatives that are physically feasible and realizable within schedule requirements and available resources
  - Recommend a preferred course of action

# 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

# System Design and Feasibility Analysis

- It is a this early stage of the system life-cycle that **major decisions** are made relative to adopting specific:
    - **Design approach**
    - **Related technology application**
- At this stage, results of such design decisions can have a great impact on
    - **The ultimate behavioral characteristics**
    - **Life-cycle cost of a system**

**Note:** In some cases, there is not enough information on the technology applications, research maybe initiated to develop a new knowledge

The **“need”** should dictate and drive the **“technology”** and not vice versa

# System Operational Requirements

- Once the **need** and **technical approach** have been identified, it is necessary to translate them into an **Operational Scenarios** or set of operational requirements
- At this point, slew of questions maybe asked:
    - *What are the anticipated types and quantities of equipment, software, personnel, facilities, information, and so on required*
    - *Where they to be located?*
    - *How is the system to be utilized and for how long?*
    - *What are the expected interoperability requirements?*
    - *And etc…*

***Note: Answer of these questions lead to the definition of system operational requirement, the follow-on maintenance and support concept, and the identification of specific design-to criteria and related guidelines***

# System Operational Requirements

- **Defining System Operational Requirements**

  System operational requirements should be **identified and defined early, carefully, and as complete as possible** based on an **established need and selected technical approach**

- **Operational concept and scenarios:**
  - *Mission Definition:* Identification of the prime and alternate or secondary missions of the system
  - *Performance and physical parameters*: Operating characteristics or functions of the system (e.g., size, weight, speed, range, flow rate, etc). What are the critical system performance parameters? How are related to the mission scenarios
  - *Operational deployment or distribution*: The proposed bridge – the location shall be based on the results of the study dealing with geological, geotechnical, hydrology, etc
  - *Operational life cycle*: The proposed bridge shall be constructed and fully operational 5 years from the date of initial contract award, and the operational life cycle shall be 50 years
  - *Effectiveness factors*:
    - Operation availability (Ao) for the overall system shall be 99.5%
    - MTBM shall be 5 years or greater
    - Maintenance downtime (MDT) shall be 1 day or less

# System Operational Requirements

- **Operational concept and scenarios: (Cont…)**
  - *Environmental factors*: The proposed bridge shall be fully operational in an environment with –
    - Temperatures ranging +125F to -50F ambient
    - 100% humidity
    - In rain, sleet and/or snow
    - Withstand any shock and vibration due to a fully loaded traffic flow
    - Withstand any earth tremors of up to 6.0 on the Richter Scale
    - Etc…
  - *Environment sustainment factors*: There will be NO
    - Degradation to the river flow
    - Adjoining river embankment
    - Air quality
    - View-scope aesthetics
    - Etc…
  - *Economic factors*: Bridge should be designed such that –
    - Projected life cycle cost (LCC) not to exceed $X
    - Annual operation and maintenance cost exceed 1%

# System Operational Requirements

- **Operational concept and scenarios: (Cont.)**

Note: While some of the specific design-to qualitative and quantitative factors introduced may vary from one project to the next.

**Illustrations:**

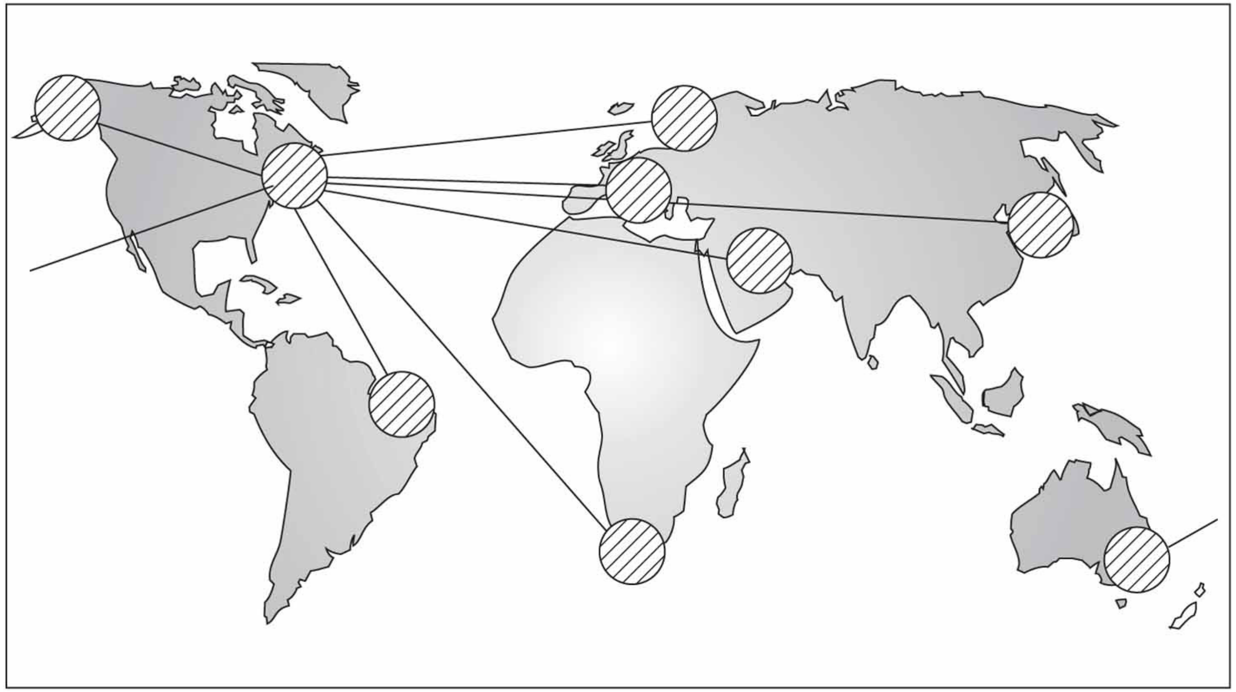
- **Aircraft System**
- **Communication System**
- **Commercial Airline Upgrade**
- **Community Hospital**

**Additional Illustrations – SOS (System-of- System)**

The 5 illustration presented, requirements must be implemented within the bounds of the specific system configuration but also consider all possible external interfaces that may exist

- There may be some “sharing” of capabilities across the board
- The air and ground transportation systems utilizing some of the same components which operate as part of the communication systems

**Figure 3.3** System operational requirements (distribution and utilization).



Number of Units in Operational Use per Year

| Geographical Operational Areas | Year Number | | | | | | | | | | Total Units |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 1. North and South America | – | – | 10 | 20 | 40 | 60 | 60 | 60 | 35 | 25 | 310 |
| 2. Europe | – | – | 12 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 180 |
| 3. Middle East | – | – | 12 | 12 | 12 | 24 | 24 | 24 | 24 | 24 | 156 |
| 4. South Africa | – | – | 12 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 180 |
| 5. Pacific Rim 1 | – | – | 12 | 12 | 12 | 24 | 24 | 24 | 12 | 12 | 132 |
| 6. Pacific Rim 2 | – | – | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 96 |
| Total | – | – | 70 | 104 | 124 | 168 | 168 | 168 | 131 | 121 | 1,054 |

Average Utilization: 4 Hours per Day, 365 Days per Year

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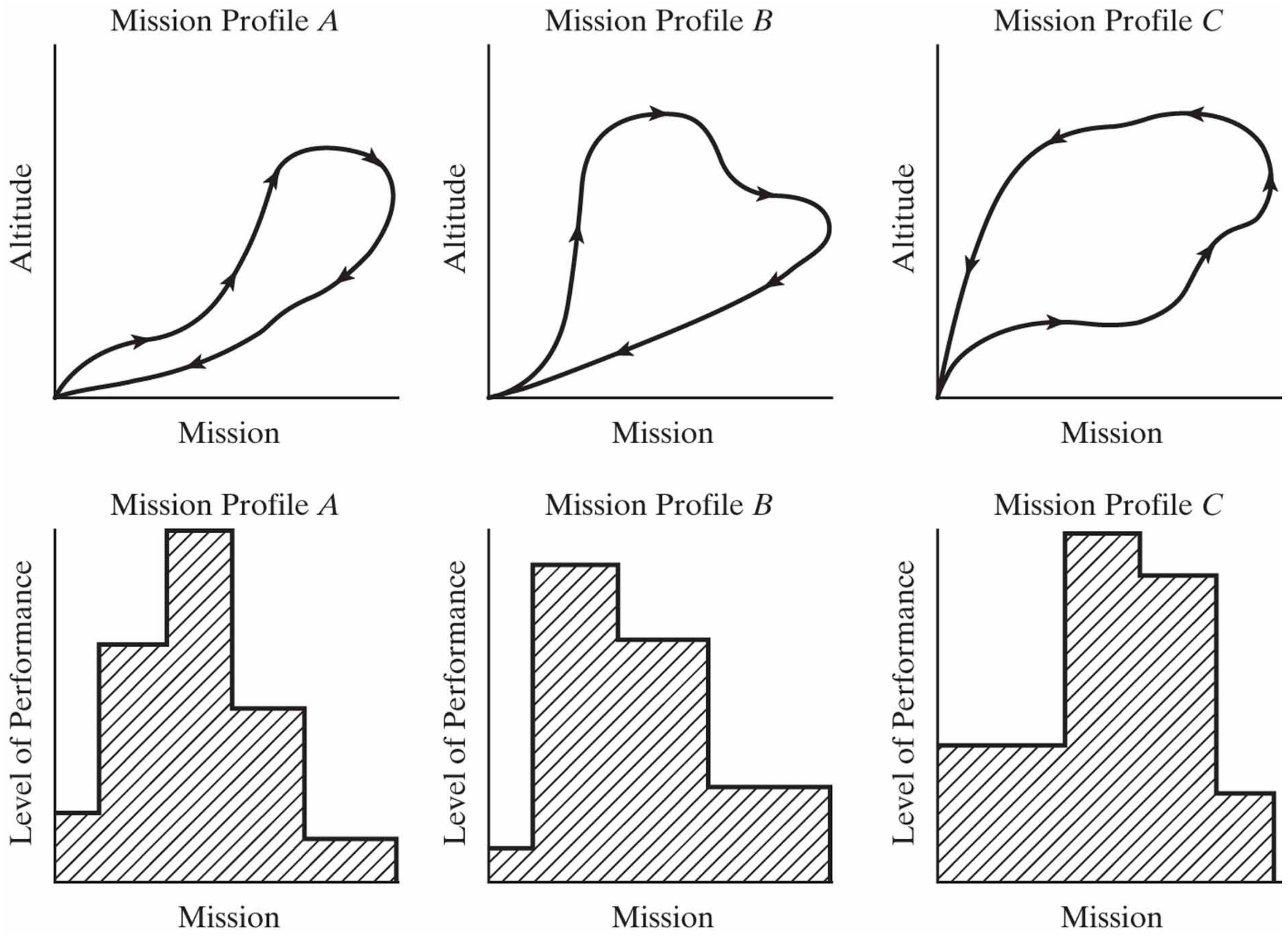
**Figure 3.4** Typical aircraft operational profiles.

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# Figure 3.5 Top-level system maintenance and support infrastructure

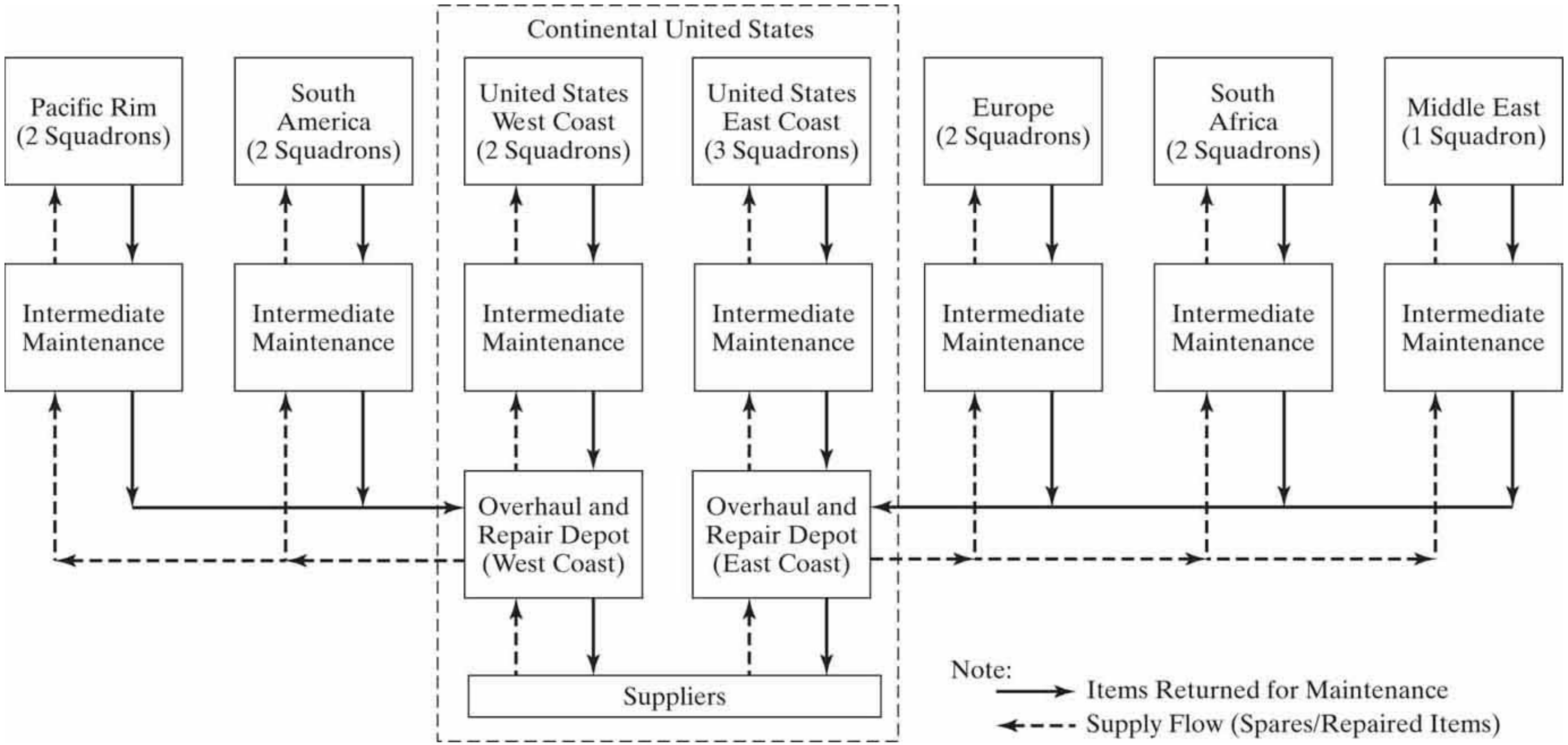


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**Figure 3.6** Mission profile.

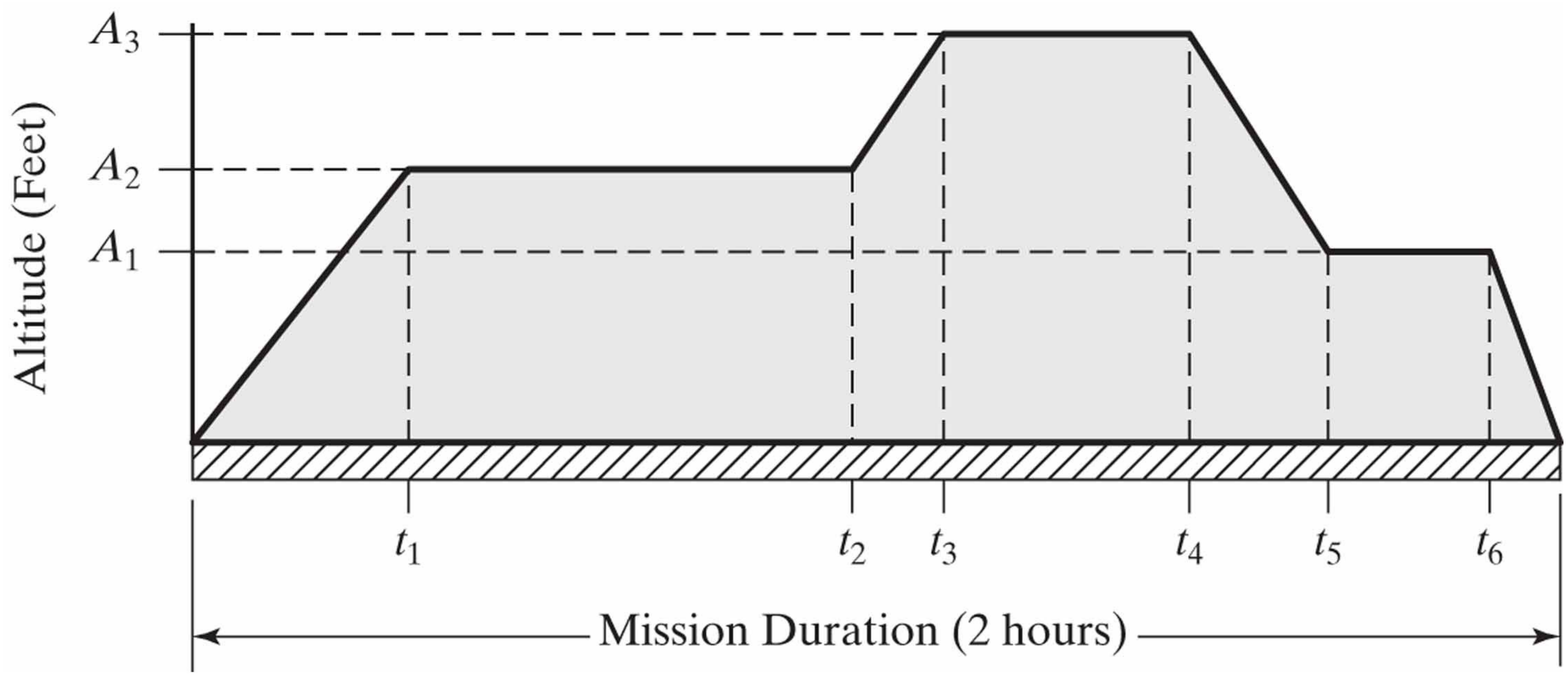


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**Figure 3.7** Program schedule.

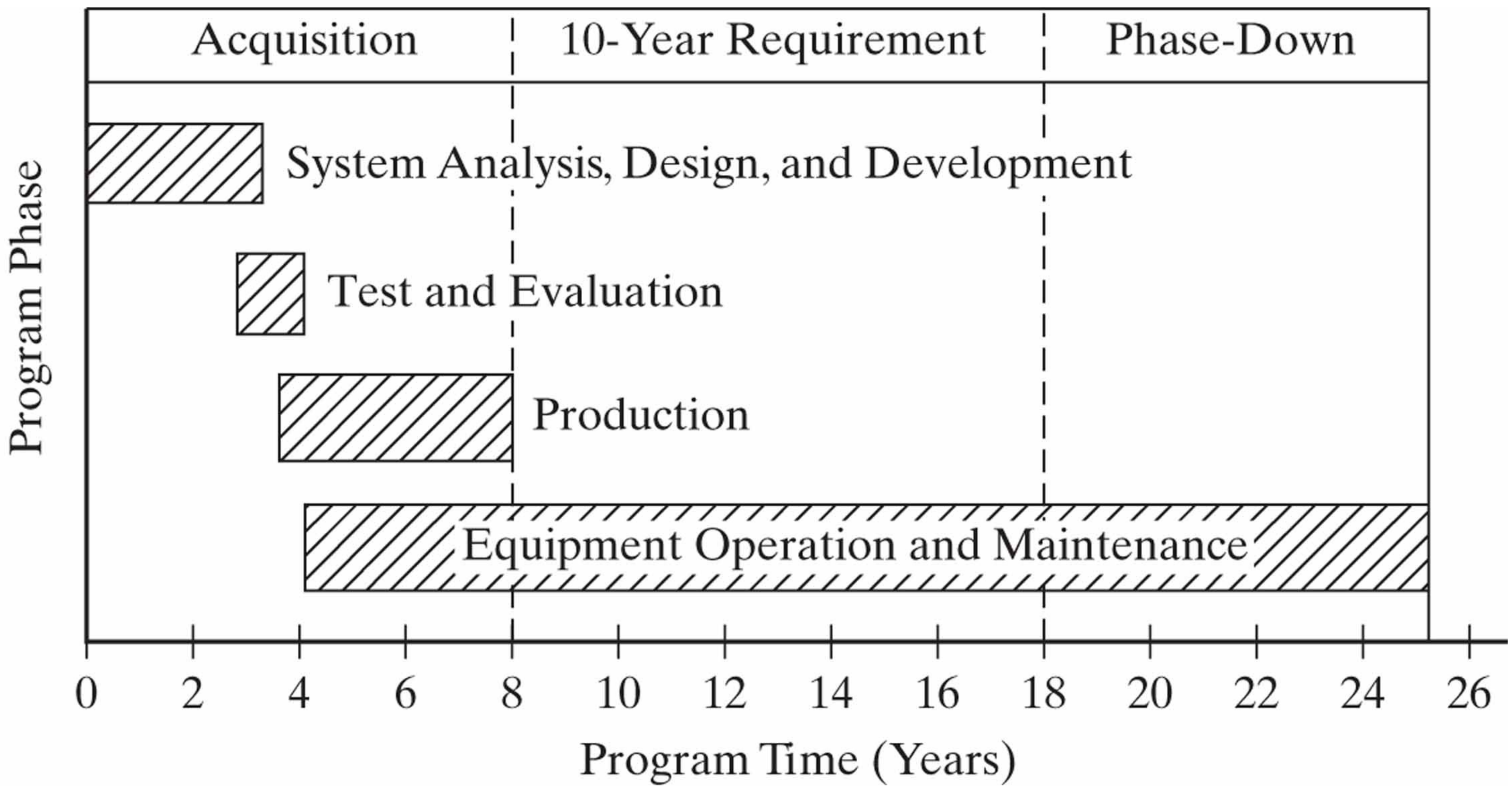


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**Figure 3.8** Communication network (typical).

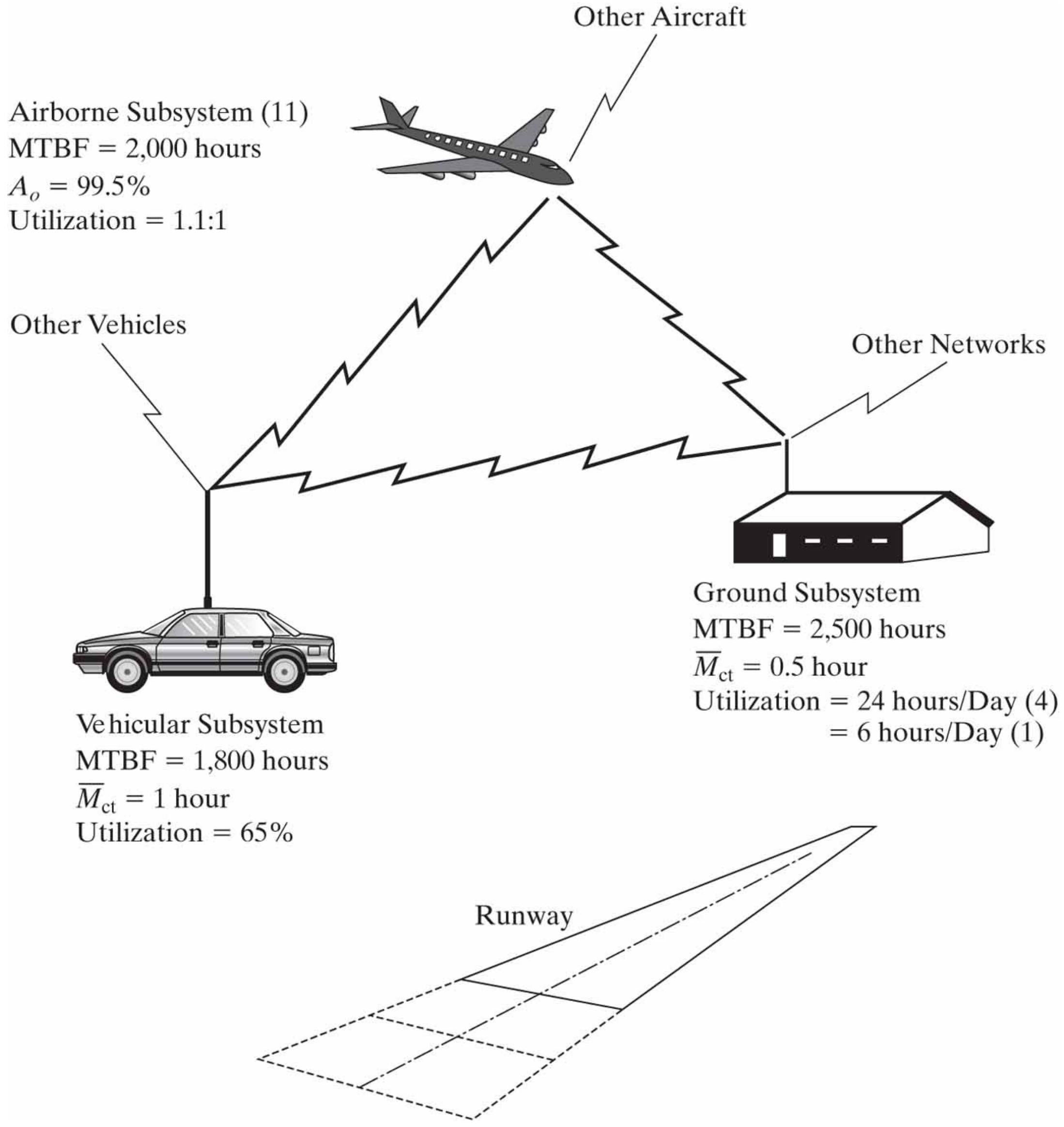


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**Figure 3.9** Basic inventory requirements over the system life cycle.

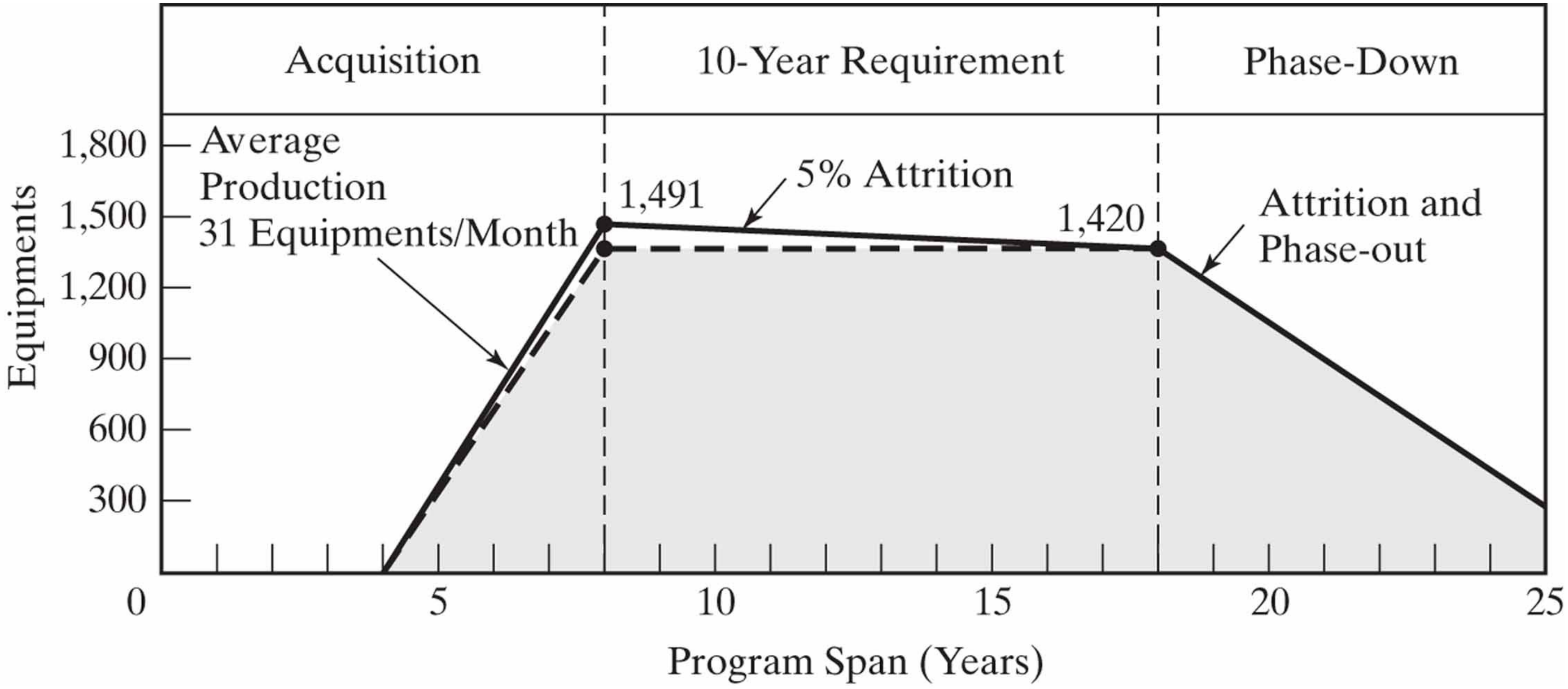


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**Figure 3.10** Projected passenger-handling requirement

| Time Period | Anticipated Flights per Day | | | |
|---|---|---|---|---|
| | Point *A* | Point *B* | Point *C* | Point *D* |
| 6:00 A.M. – 11:00 A.M. | 33 | 65 | 95 | 105 |
| 11:00 A.M. – 4:00 P.M. | 17 | 43 | 50 | 55 |
| 4:00 P.M. – 9:00 P.M. | 33 | 60 | 90 | 100 |
| 9:00 P.M. – 6:00 A.M. | 3 | 10 | 15 | 18 |
| Total | 86 | 178 | 250 | 278 |

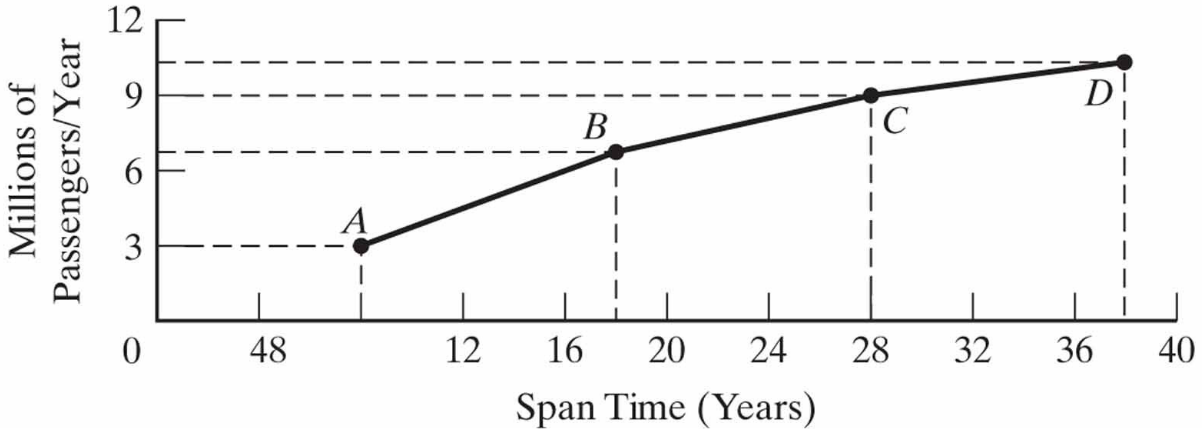


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**Figure 3.11** Program schedule.

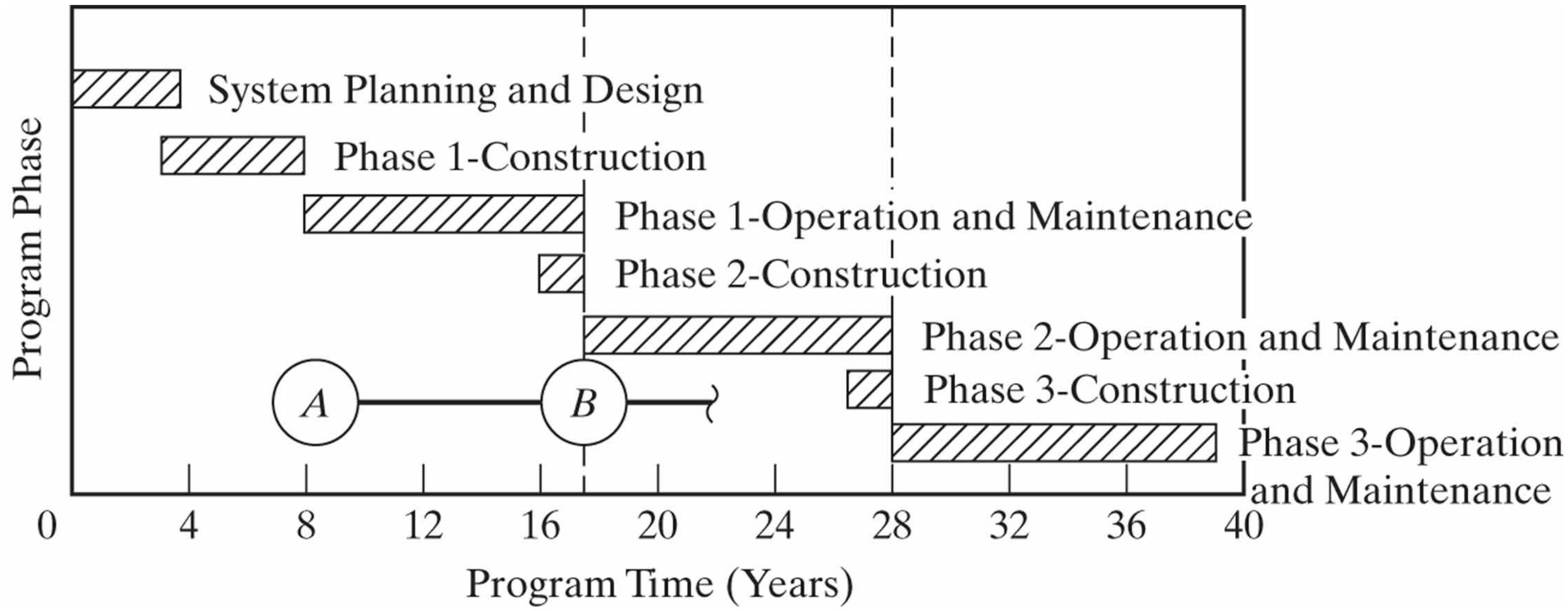


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**Figure 3.12** Community healthcare infrastructure.

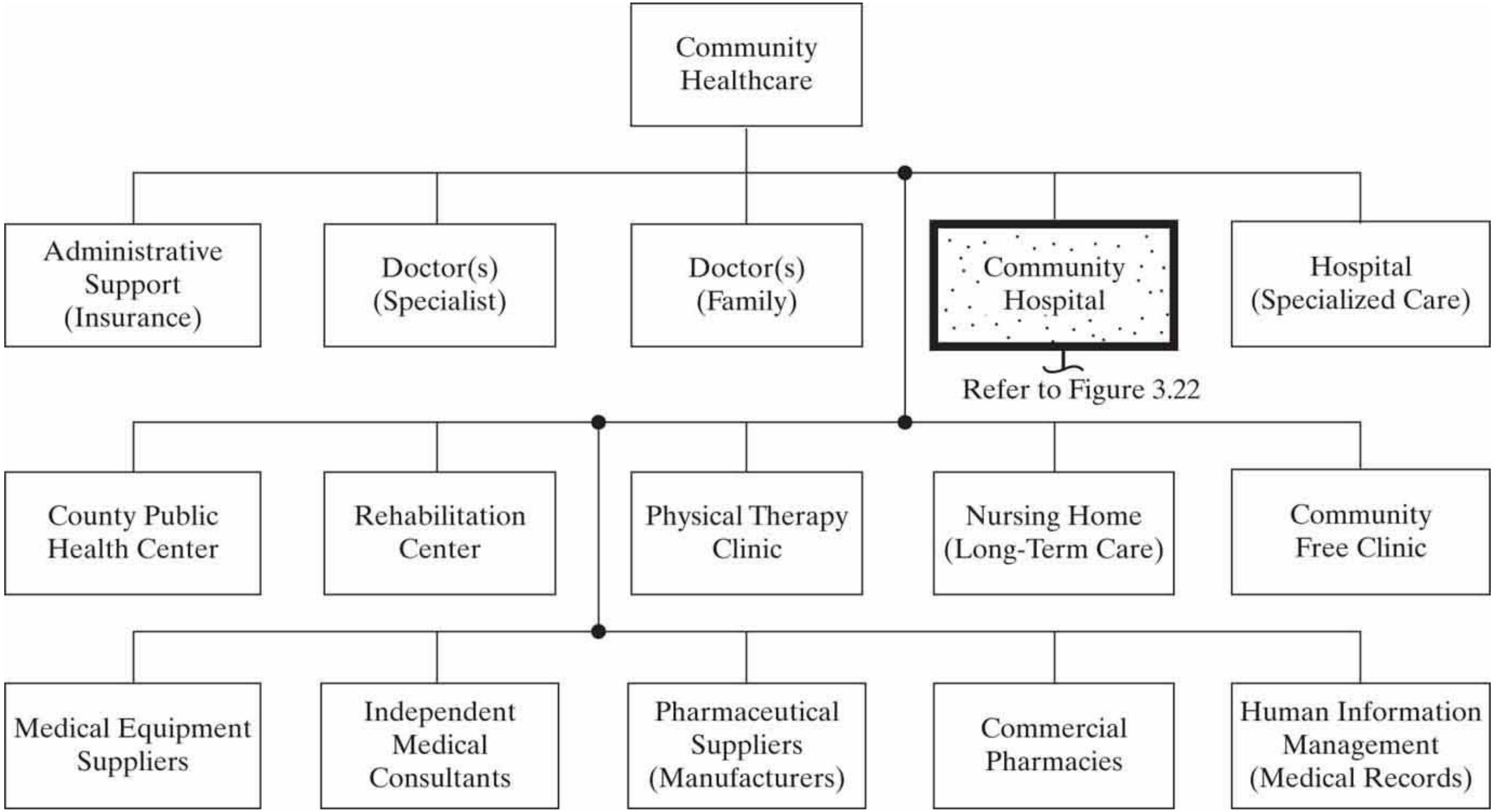


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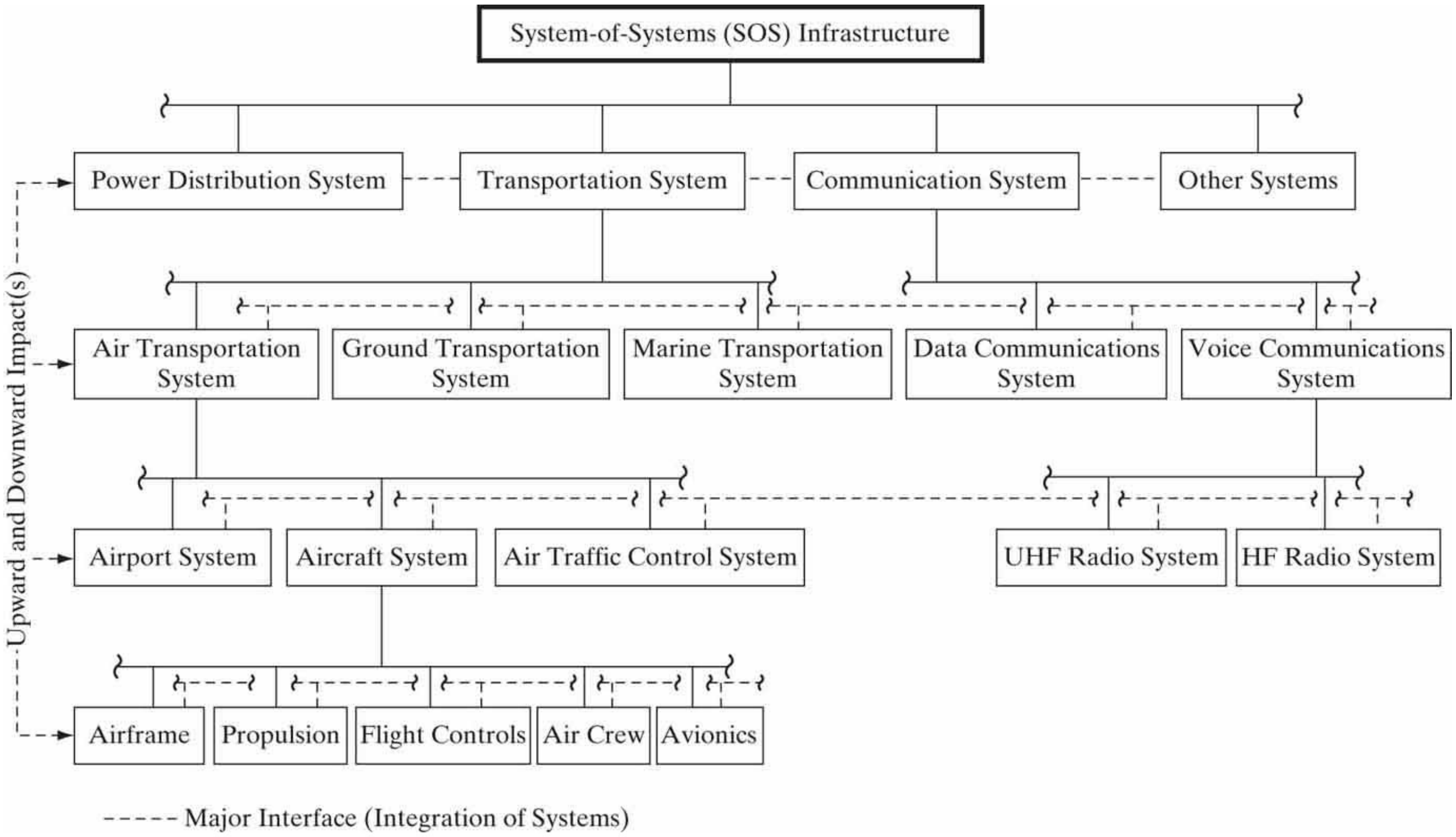
**Figure 3.13** Multiple systems (system-of-systems).

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# System Maintenance and Support

- **<u>Note</u>**: In general, the emphasis has been directed toward ***only part of the system*** and not the entire system as an entity, which led to costly results in the past

- The prime system elements must be designed in such way that they can be effectively and efficiently supported through the entire system life-cycle –
    - The **maintenance** and **support infrastructure** must be responsive to this requirement

    (transportation, handling equipment, test and support equipment, maintenance facilities, supply chain process, and logistics support, etc…)
    - The maintenance and support concept developed during conceptual design phase evolves from **the System Operational requirements** described above

- The maintenance and support concept is reflected by **the network and the activities and their interrelationships** Fig. 3.14

# System Maintenance and Support

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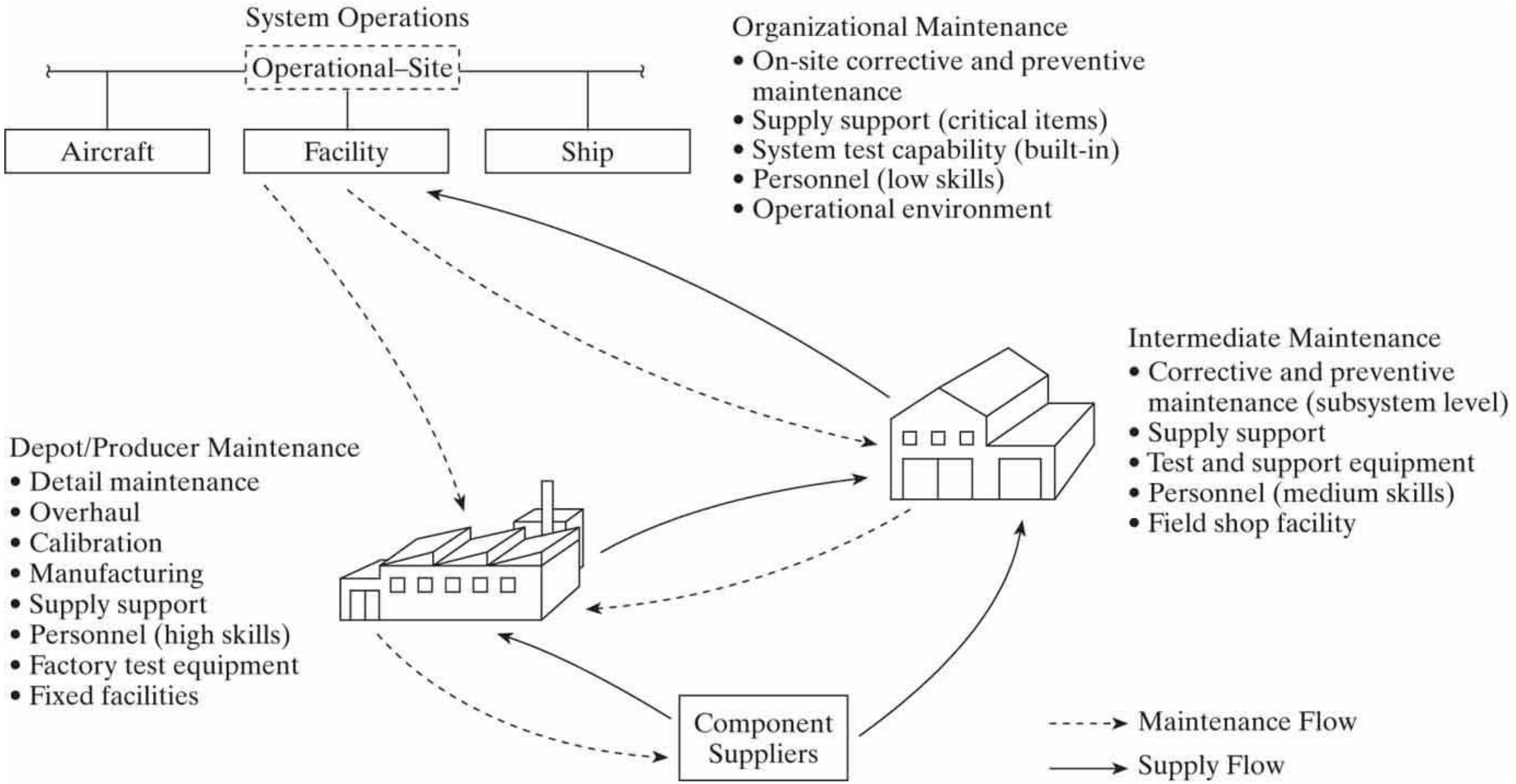
**Figure 3.14** System operational and maintenance flow.

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# System Maintenance and Support

- The maintenance and support concept in general includes the following items:
  - ***Levels of Maintenance***:

  Corrective and preventive maintenance may be performed on the system itself, or element thereof, at the system operating's site, in an intermediary shop near the customer's operational site, and/or at a depot or manufacturer facility

    - Maintenance level pertains to the division of functions and tasks for each area where maintenance is performed:
      - Anticipated frequency of maintenance, task complexity, personnel skills, special facility needs, etc
      - Depending on the needs, there may be two, three, or four levels of maintenance
      - Maintenance classifications: *Organizational, intermediate, and Manufacturer/Depot/Supplier* Fig. 3.15
  - ***Repair Policies:***

  There are a number of possible policies specifying the extent to which the repair of a compnent should be accomplished

  Early guidelines for the design of the components Fig. 3.16

**Figure 3.15** Major levels of maintenance.

| Criteria | Organizational Maintenance | Intermediate Maintenance | | Supplier/Manufacturer/Depot Maintenance |
|---|---|---|---|---|
| Done where? | At the operational site or wherever the prime elements of the system are located | Mobile or semimobile units | Fixed units | Supplier/manufacturer/depot facility |
| | | Truck, van, portable shelter, or equivalent | Fixed field shop | Specialized repair activity or manufacturer's plant |
| Done by whom? | System/equipment operating personnel (low-maintenance skills) | Personnel assigned to mobile, semimobile, or fixed units (intermediate-maintenance skills) | | Depot facility personnel or manufacturer's production personnel (high-maintenance skills) |
| On whose equipment? | Using organization's equipment | Equipment owned by using organization | | |
| Type of work accomplished? | Visual inspection<br>Operational checkout<br>Minor servicing<br>External adjustments<br>Removal and replacement of some components | Detailed inspection and system checkout<br>Major servicing<br>Major equipment repair and modifications<br>Complicated adjustments<br>Limited calibration<br>Overload from organizational level of maintenance | | Complicated factory adjustments<br>Complex equipments repairs and modifications<br>Overhaul and rebuild<br>Detailed calibration<br>Supply support<br>Overload from intermediate level of maintenance |

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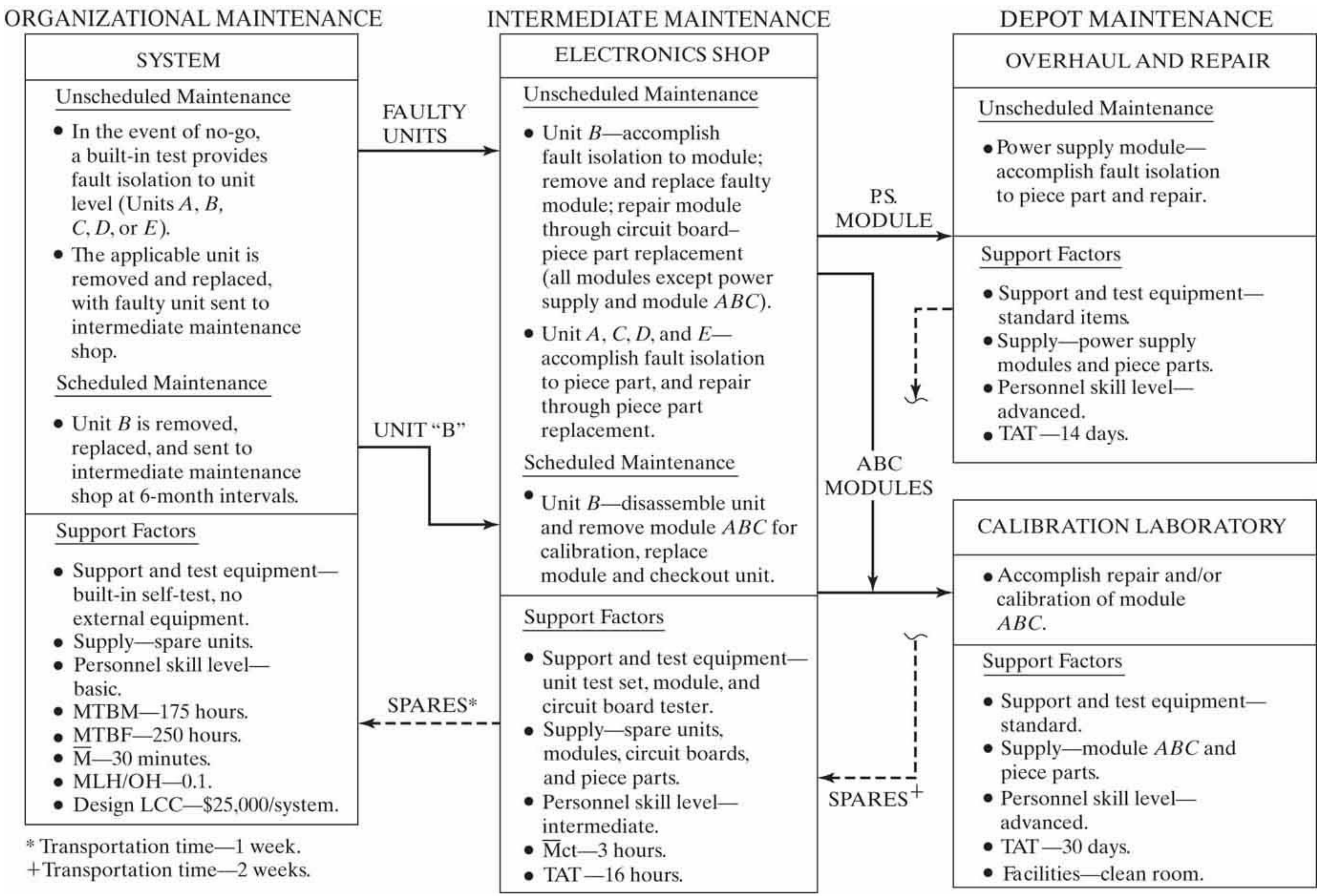
**Figure 3.16** System maintenance and repair policy.

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# System Maintenance and Support

- ***Organizational Responsibilities***

The accomplishment of maintenance may be the responsibility of the customers, the producer/supplier, combination thereof

- ***Maintenance support elements***

As part of the initial maintenance concept, criteria must be established relating to various element of maintenance support

- ***Effectiveness requirements***

These constitute the effectiveness factors associated with the support capability

In the supply support area, they may include a spare-part demand rate, the economic order quantity as related to inventory procurement. For test equipment, the length of the queue, process time, reliability factor of test equipment

- ***Environment***

Environment requirements, this includes the impact of external factors: temperature, vibration, humidity, noise, mountains versus flat terrain

# System Maintenance and Support

<u>**Note**</u>:

The maintenance concept provides the foundation that leads to:

- The design and development of the maintenance and support infrastructure and
- Defines the specific design-to requirements for the various elements of support (supply support capability, transportation and handling equipment, etc)

- The development of the maintenance concept must be accomplished **concurrently and early during the conceptual design phase**

- **System-of-systems:**

It is important that consideration be given to the interfaces that may exist between the support requirements and infrastructure for the new system being developed and those for other systems within SoS

# Technical Performance Measures (TPMs)

TPMs are **quantitative values** (*estimated, predicted, and/or measured*) that describe system performance

**The TPMs objective** is to ***influence*** the system design process to incorporate the right attributes/characteristics that will meet the customer requirements

TPMs are measures of the **attributes and/or characteristics** that are inherent within the design

**DDPs** (Design-Depend Parameters) are the bases for the determination of TPMs

***TPM identification and evolution***

May include such quantitative factors as:

- Reliability MTBF
- Maintainability MTBM
- MDT (Maintenance Down Time)
- Ao (Availability Operational)
- Logistics response time, facility utilization rate, LCC (Life-Cycle Costs), and so on

# Technical Performance Measures (TPMs)

TPMs ***evolve*** primarily from the development of *the system operational requirements and the maintenance /support concepts*

***<u>Note:</u>*** *Some of these specified values may be contradictory to determine which characteristics that need to be include in the design:*

Vehicle design: speed vs size

Communication system: range vs clarity

Is reliability more important than maintainability?

AS human-factor more important than LCC

Team (customer, designers, maintenance/support, suppliers, etc) conveyed the TPMs results Fig. 3.17

Critical TPMs are identified along with their relative degrees of importance: *Velocity, availability,* and *size* are the most critical TPMs

**<u>Note:</u> There must be a traceability of requirements from the system level down to its various 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<br>6 feet wide<br>4 feet high<br>(maximum) | 9 feet long<br>8 feet wide<br>4 feet high<br>(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 |

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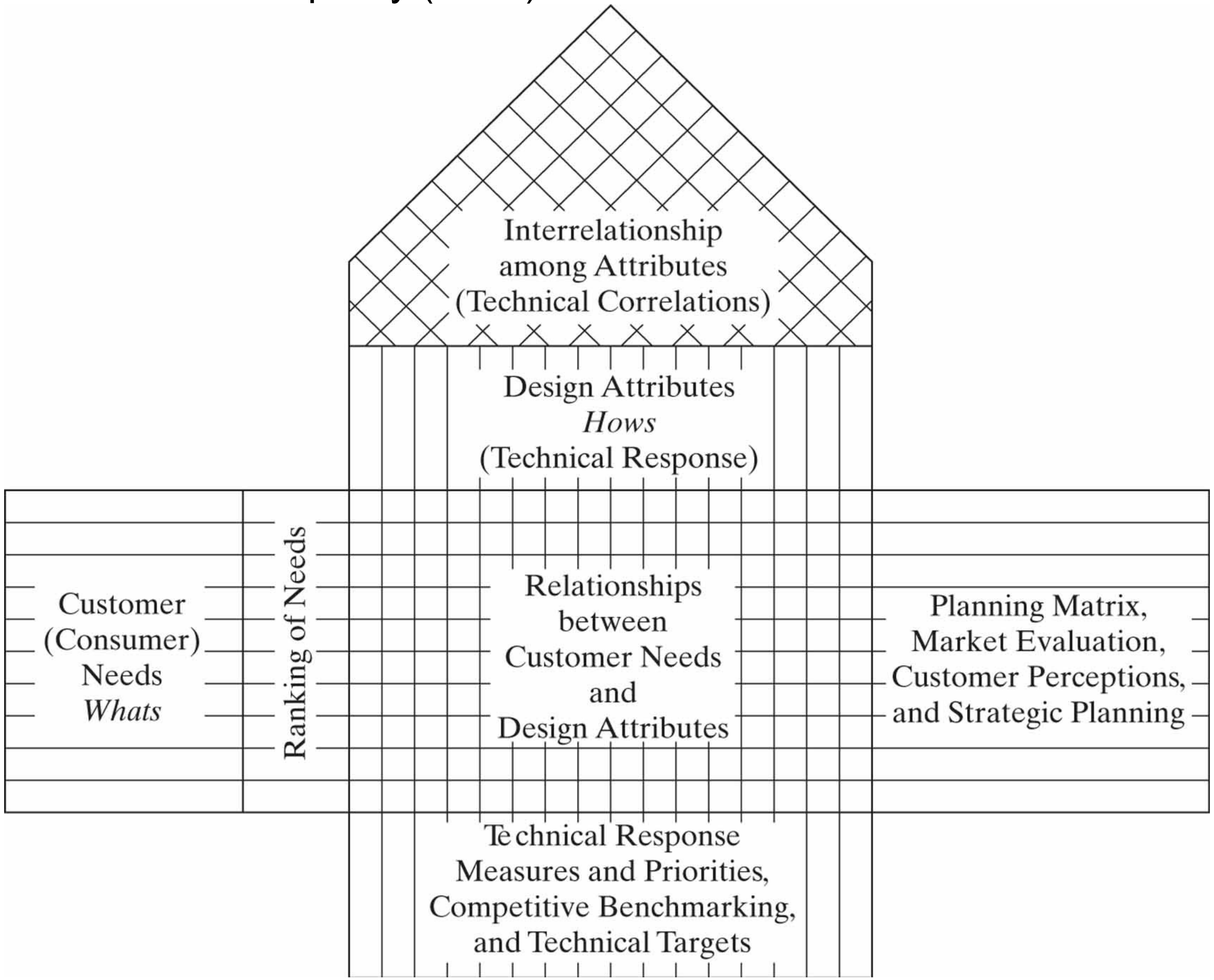
# Quality Function Deployment (QFD)

- QFD is useful to aid in the establishment and prioritization of TPMS
- QFD constitutes a team approach to help ensure that the ***"voice of the customer"*** is reflected in the design
- The purpose is to establish the necessary requirements and to translate them into technical solutions
- The are defined and classified as attributes which are then weighted based on the degree of importance. QFD provides to:
  - Design team to understand the customer desires
  - Forces the customer to prioritize, and
  - Enable a comparison of one design approach against another
  - Satisfy each customer attribute by technical technical solution

**Figure 3.18** Modified house of quality (HOQ).

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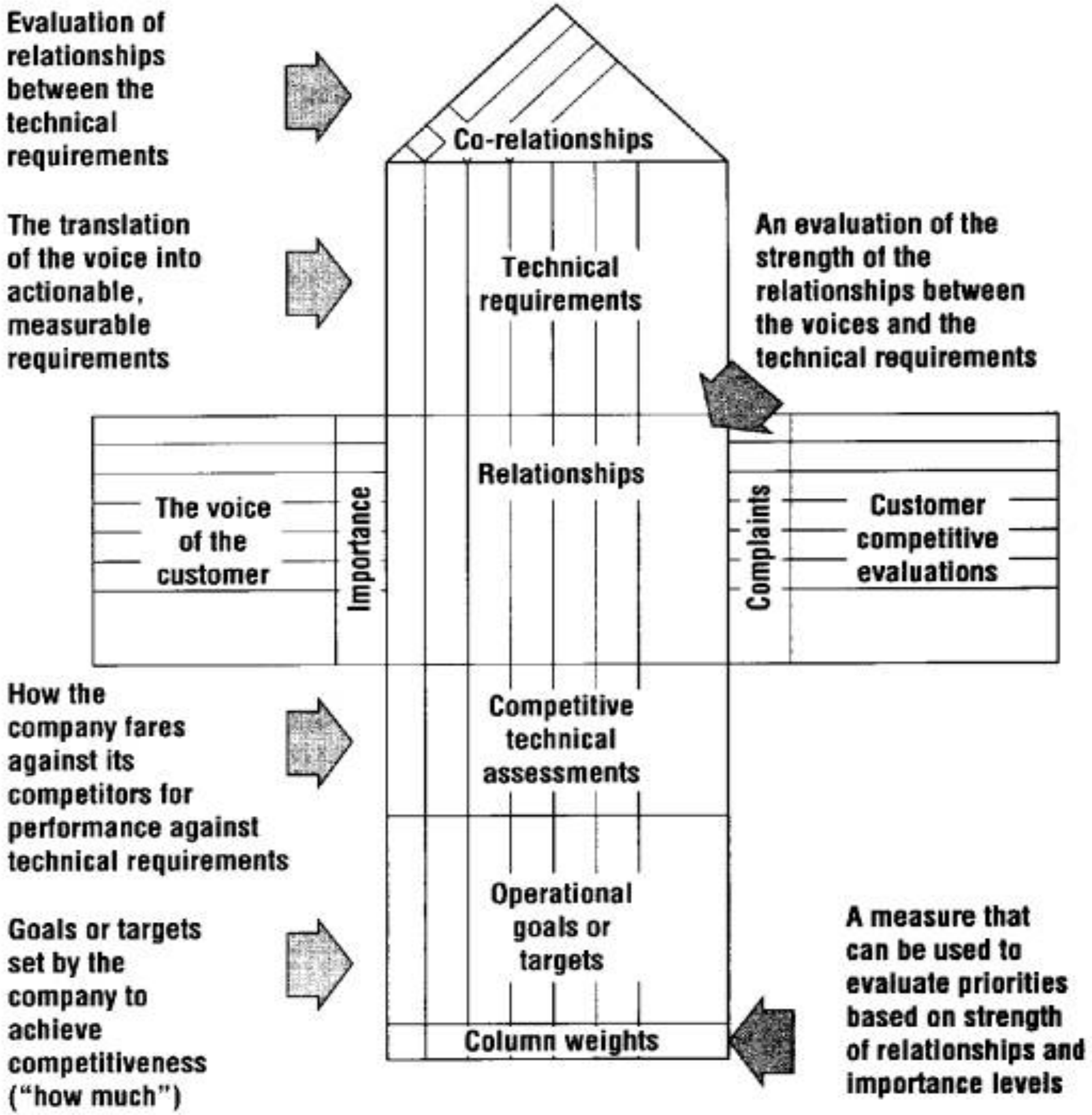
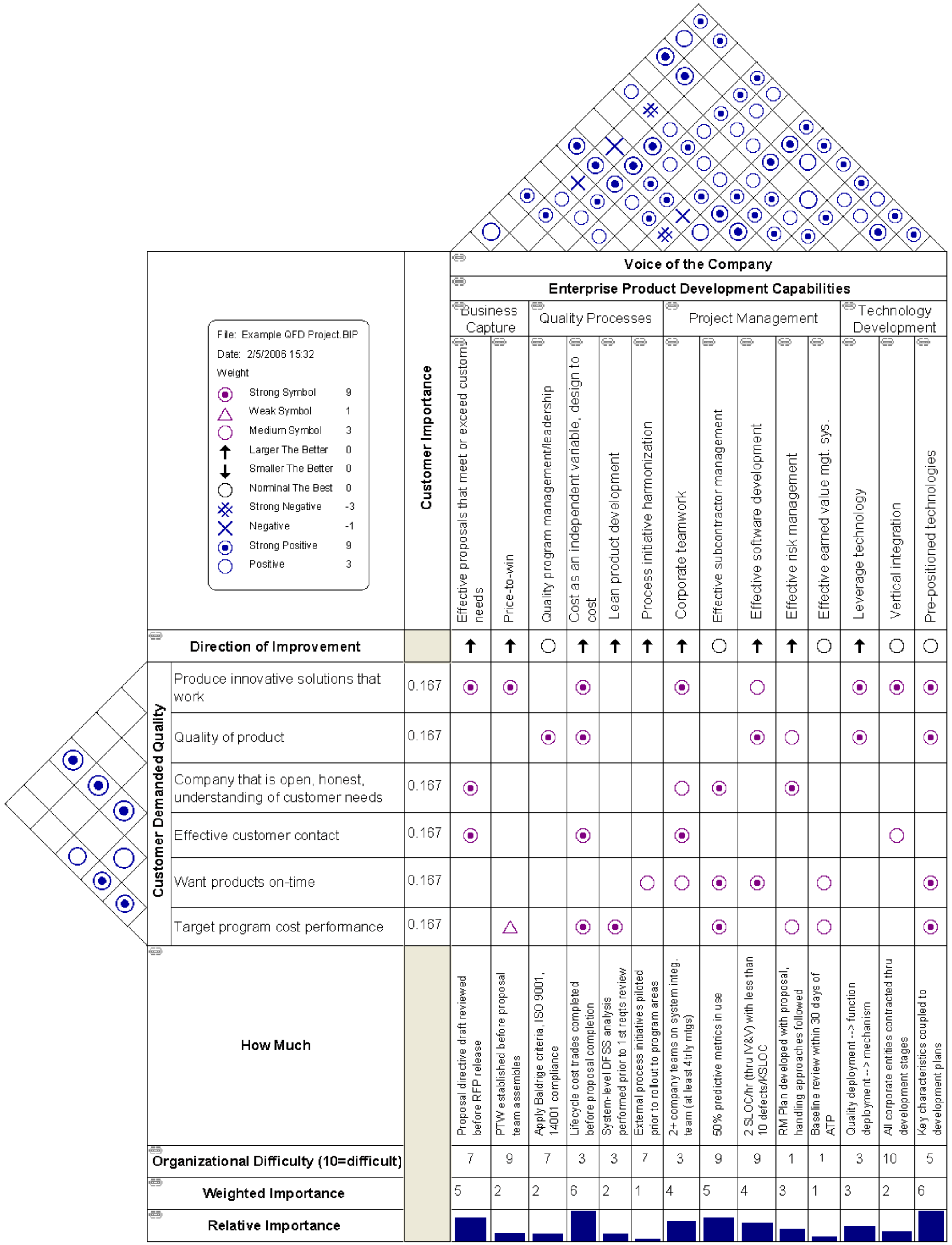


Evaluation of relationships between the technical requirements
Co-relationships
The translation of the voice into actionable, measurable requirements
Technical requirements
An evaluation of the strength of the relationships between the voices and the technical requirements
Relationships
The voice of the customer
Importance
Complaints
Customer competitive evaluations
How the company fares against its competitors for performance against technical requirements
Competitive technical assessments
Goals or targets set by the company to achieve competitiveness ("how much")
Operational goals or targets
A measure that can be used to evaluate priorities based on strength of relationships and importance levels
Column weights


File: Example QFD Project.BIP
Date: 2/5/2006 15:32
Weight
Strong Symbol 9
Weak Symbol 1
Medium Symbol 3
Larger The Better 0
Smaller The Better 0
Nominal The Best 0
Strong Negative -3
Negative -1
Strong Positive 9
Positive 3
Customer Importance
Voice of the Company
Enterprise Product Development Capabilities
Business Capture
Quality Processes
Project Management
Technology Development
Effective proposals that meet or exceed customer needs
Price-to-win
Quality program management/leadership
Cost as an independent variable, design to cost
Lean product development
Process initiative harmonization
Corporate teamwork
Effective subcontractor management
Effective software development
Effective risk management
Effective earned value mgt. sys.
Leverage technology
Vertical integration
Pre-positioned technologies
Direction of Improvement
Customer Demanded Quality
Produce innovative solutions that work 0.167
Quality of product 0.167
Company that is open, honest, understanding of customer needs 0.167
Effective customer contact 0.167
Want products on-time 0.167
Target program cost performance 0.167
How Much
Proposal directive draft reviewed before RFP release
PTW established before proposal team assembles
Apply Baldrige criteria, ISO 9001, 14001 compliance
Lifecycle cost trades completed before proposal completion
System-level DFSS analysis performed prior to 1st reqts review
External process initiatives piloted prior to rollout to program areas
2+ company teams on system integ. team (at least 4/rly mtgs)
50% predictive metrics in use
2 SLOC/hr (thru IV&V) with less than 10 defects/KSLOC
RM Plan developed with proposal, handling approaches followed
Baseline review within 30 days of ATP
Quality deployment --> function deployment --> mechanism
All corporate entities contracted thru development stages
Key characteristics coupled to development plans
Organizational Difficulty (10=difficult) 7 9 7 3 3 7 3 9 9 1 1 3 10 5
Weighted Importance 5 2 2 6 2 1 4 5 4 3 1 3 2 6
Relative Importance

# Quality Function Deployment (QFD)

- QFD method is used to facilitate the **translation** of a prioritized **set of subjective customer requirements** into a **set of system-level requirements**

- Similar approach to subsequently translate system-level requirements into more detailed set of requirements (subsystem- level, component level, Manufacturing requirements, etc)

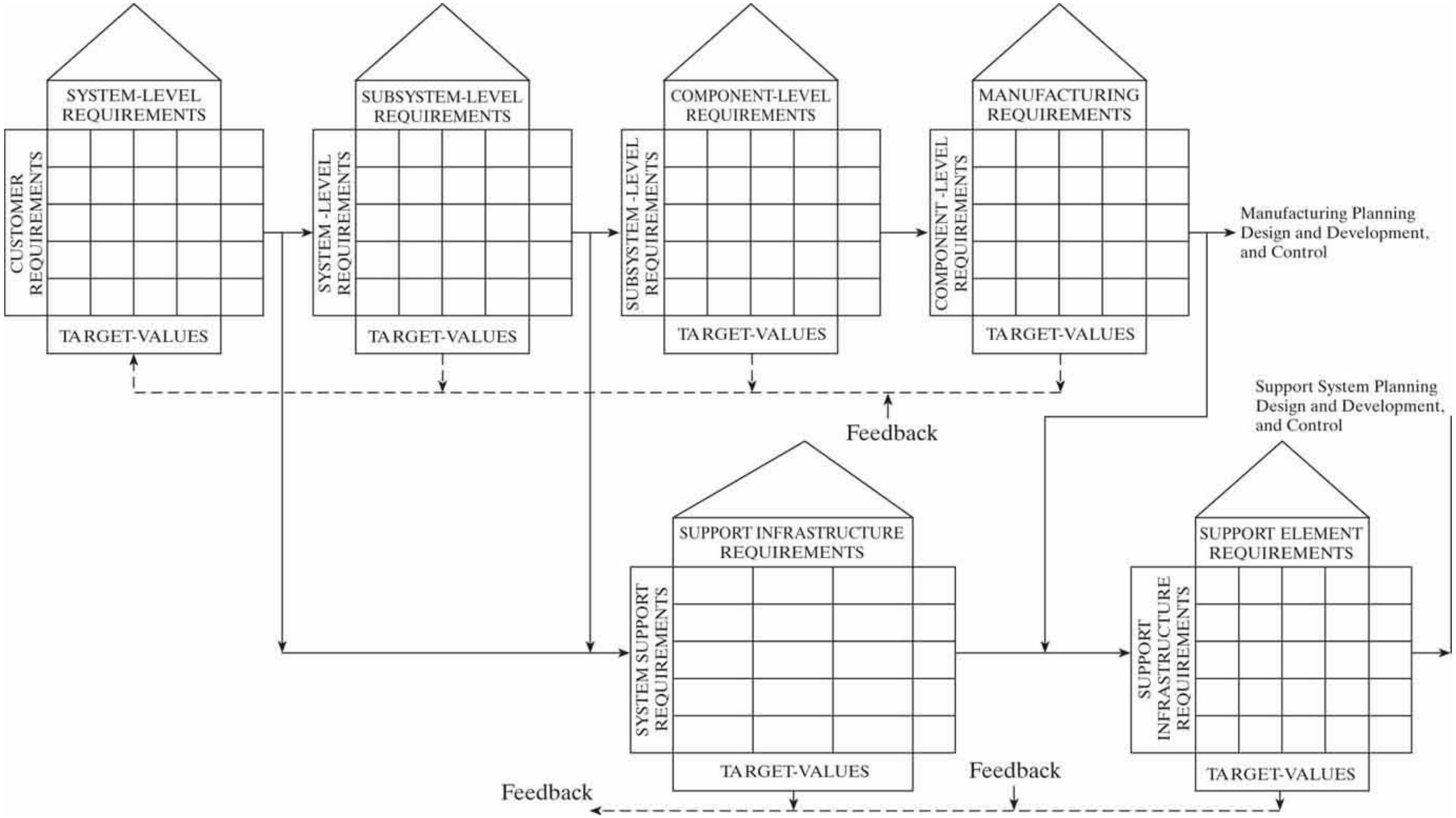
    - ***Whats***
    - ***Hows***

- QFD method is to ensure the **required justification** and **traceability** of requirements from **the top down**

**Note:**

Further, requirements should be stated in ***functional terms***

**Figure 3.19** The traceability of requirements through a "family of houses."

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# Assignment 3

Based on your selected team project:

1) In accomplishing the need analysis, What type of information you would include, Describe the process, Develop the need analysis
2) In the accomplishing the feasibility analysis, What considerations should be addressed for your project in the completion of this task, Develop the feasibility analysis
3) In accomplishing the system operational requirements, describe your process and type of information needed, Develop the Operational requirements
4) Describe the QFD approach for your projects and how it could be applied, Develop QFD for your project
5) Describe the Functional Analysis approach for your projects and how it could be applied