Chapter 4

Preliminary System Design
What is it?

- Developing design requirements from system-level requirements for subsystems and major system elements
- Preparing *development, product, process, and material* specifications that are applicable to subsystems
- Accomplishing functional analysis and allocation at the and below the subsystem level
- Establishing detailed design requirements and developing plans for their allocation to engineering specialties
- Identifying and utilizing appropriate engineering design tools and technologies
- Conducting trade-off studies for both design and operational effectiveness
- Conducting design reviews at predetermined points in time

Preliminary System Design Process
Program Documentation Tree

Program Requirements

Program Management Plan

System XYZ Specification (Type A)

Software Development Specification (Type B)

Computer Program Product Specification (Type C)

Equipment Development Specification (Type B)

Unit A Product Specification (Type C)

Special Test Equipment Product Specification (Type C)

Unit B Development Specification (Type B)

Assembly 1 Process Specification (Type D)

Subassemblies Material Specification (Type E)

System Engineering Management Plan (SEMP)

Part I
Technical Program Planning and Control

Part II
System Engineering Process

Part III
Engineering Specialty Integration
Program Documentation Tree

- System Specification (Type A)
  - Technical, performance, operational, and support characteristics
  - Results of feasibility analysis
  - Operational requirements
  - Maintenance and support concept
  - Appropriate TPMs
  - Functional description
  - Design requirements
  - Subsystem allocation

- Development Specification (Type B)
  - Technical requirements for items below system level
  - Similar to System Specification
Program Documentation Tree

- Product Specification (Type C)
  - Technical requirements of “off-the-shelf” items below system level

- Process Specification (Type D)
  - Technical requirements associated with processes
  - Technical requirements associated with services

- Material Specification (Type E)
  - Technical requirements of raw materials
Identification of Resource Requirements (mechanisms)

(Refer to Figure 3.21)

1.0 Identify Need and Determine System Requirements
2.0 Design and Develop System
3.0 Manufacture System (Production)
4.0 Operate and Maintain System

CONTROLS/CONSTRAINTS
- Technical
- Political
- Sociological
- Economic
- Environmental

FUNCTION
- System/product ready for consumer use
- Supporting resources
- Waste (residue)

INPUTS
- System requirements
- Organizational structure
- Raw materials
- Data/documentation

OUTPUTS
- Human resources
- Materials/liquids
- Computer resources
- Facilities/utilities
- Maintenance and support

MECHANISMS
Some Documentation Formats

<table>
<thead>
<tr>
<th>Activity Number</th>
<th>Activity Description</th>
<th>Required Inputs</th>
<th>Expected Outputs</th>
<th>Resource Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Need identification</td>
<td>Customer surveys; marketing inputs; shipping and servicing department logs; market niche studies; competitive product etc.</td>
<td>A specific qualitative and quantitative needs statement responding to a current deficiency. Care must be taken to state this need in functional terms.</td>
<td>Benchmarking; statistical analyses of data (i.e., data collected as a result of surveys and consolidated from shipping and servicing logs, etc.)</td>
</tr>
<tr>
<td>2.1</td>
<td>Needs analysis and requirements definitions</td>
<td>A specific qualitative and quantitative needs statement expressed in functional terms.</td>
<td>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.</td>
<td>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.</td>
</tr>
<tr>
<td>2.2</td>
<td>Synthesis of conceptual system design alternatives</td>
<td>Results from needs analysis and requirements definition process; technology research studies; supplier information.</td>
<td>Identification and description of candidate conceptual system design alternatives and technology applications.</td>
<td>Pugh’s concept generation approach; brainstorming; analogy; checklists.</td>
</tr>
<tr>
<td>2.3</td>
<td>Analysis of conceptual system design alternatives</td>
<td>Candidate conceptual solutions and technologies; results from the needs analysis and requirements definition process.</td>
<td>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.</td>
<td>Indirect system experimentation (e.g., mathematical modeling and simulation); parametric analyses; risk analyses.</td>
</tr>
<tr>
<td>2.4</td>
<td>Evaluation of conceptual system design alternatives</td>
<td>Results from the analysis task in the form of a set of feasible conceptual system design alternatives.</td>
<td>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.</td>
<td>Design-dependent parameter approach; generation of hybrid numbers to represent candidate solution “goodness”; conceptual system design evaluation display.</td>
</tr>
</tbody>
</table>
Functional Packaging into Major Elements

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Requirements Allocation Example

**SYSTEM XYZ**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>Mode 1 – 200 mi</td>
</tr>
<tr>
<td></td>
<td>Mode 2 – 300 mi</td>
</tr>
<tr>
<td></td>
<td>Mode 3 – 500 mi</td>
</tr>
<tr>
<td>$A_o$</td>
<td>0.9989</td>
</tr>
<tr>
<td>MTBM</td>
<td>450 hr</td>
</tr>
<tr>
<td>Met</td>
<td>0.5 hr</td>
</tr>
<tr>
<td>MLH/OH</td>
<td>0.2</td>
</tr>
<tr>
<td>Skill level</td>
<td>GS-5</td>
</tr>
<tr>
<td>Cost</td>
<td>$50,000</td>
</tr>
</tbody>
</table>

**LEGEND**
- $A_o$ = Operational availability
- MTBM = Mean time between maintenance
- MLH/OH = Maintenance labor hours per operating hour
- Met = Mean corrective maintenance time
- $\lambda$ = Failure rate
- Skill level = personnel ability (i.e., grade)

**UNIT A**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTBM</td>
<td>4,050 hr</td>
</tr>
<tr>
<td>Met</td>
<td>0.9 hr</td>
</tr>
<tr>
<td>MLH/OH</td>
<td>0.02</td>
</tr>
<tr>
<td>Skill level</td>
<td>GS-7</td>
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<tr>
<td>Size (ft)</td>
<td>1.2 x 2.5 x 3.5</td>
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<tr>
<td>Weight</td>
<td>280 lb</td>
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<tr>
<td>Cost</td>
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**UNIT B**

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<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTBM</td>
<td>536 hr</td>
</tr>
<tr>
<td>Met</td>
<td>0.4 hr</td>
</tr>
<tr>
<td>MLH/OH</td>
<td>0.17</td>
</tr>
<tr>
<td>Skill level</td>
<td>GS-7</td>
</tr>
<tr>
<td>Size (ft)</td>
<td>1.1 x 8 x 2.6</td>
</tr>
<tr>
<td>Weight</td>
<td>150 lb</td>
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<tr>
<td>Cost</td>
<td>$25,000</td>
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</table>

**UNIT C**

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<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTBM</td>
<td>9,050 hr</td>
</tr>
<tr>
<td>Met</td>
<td>1 hr</td>
</tr>
<tr>
<td>MLH/OH</td>
<td>0.01</td>
</tr>
<tr>
<td>Skill level</td>
<td>GS-7</td>
</tr>
<tr>
<td>Size (ft)</td>
<td>1.2 x 2.6 x 3.7</td>
</tr>
<tr>
<td>Weight</td>
<td>320 lb</td>
</tr>
<tr>
<td>Cost</td>
<td>$8,000</td>
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**Assembly 1**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>$\lambda$</td>
<td>0.00016</td>
</tr>
<tr>
<td>Met</td>
<td>0.5 hr</td>
</tr>
<tr>
<td>MLH/OH</td>
<td>0.015</td>
</tr>
<tr>
<td>Skill level</td>
<td>GS-9</td>
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</table>

**Assembly 2**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>$\lambda$</td>
<td>0.00155</td>
</tr>
<tr>
<td>Met</td>
<td>0.4 hr</td>
</tr>
<tr>
<td>MLH/OH</td>
<td>0.13</td>
</tr>
<tr>
<td>Skill level</td>
<td>GS-9</td>
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**Assembly 3**

<table>
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<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>$\lambda$</td>
<td>0.00020</td>
</tr>
<tr>
<td>Met</td>
<td>0.3 hr</td>
</tr>
<tr>
<td>MLH/OH</td>
<td>0.025</td>
</tr>
<tr>
<td>Skill level</td>
<td>GS-9</td>
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</table>
Functional Analysis As An Input To ... 

- Functional packaging of system elements
- Reliability analysis
- Maintainability analysis
- Human factors analysis
- Maintenance and logistics support
- Producibility and disposability analysis
- Economics analysis
Detailed Design Considerations

- Design for functional capability
- Design for reliability
- Design for maintainability
- Design for usability and safety
- Design for supportability and serviceability
- Design for producibility and disposability
- Design for affordability
INTEGRATION OF THE HARDWARE, SOFTWARE, AND HUMAN LIFE CYCLES

**Evolution of Design**

1. **System Design**
   - Functional group A hardware
   - Equipment
   - Configuration items

2. **Preliminary Design**
   - Functional group B software
   - Computer software configuration items (CSIs)
   - Coding and CSC development

3. **Detail Design and Development**
   - Functional group C human
   - Human activities/duties
   - Personal requirements

4. **System Integration and Testing**
   - Component integration and development of prototype equipment
   - Equipment testing (prototype)
   - CSU and CSC testing

5. **Production and/or Construction**
   - Evaluation (system integration and testing)
   - Day-to-day design integration activities

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**Design Requirements**

- Design for
  - Performance (electrical, mechanical, etc.)
  - Cost-system effectiveness
  - Reliability
  - Maintainability
  - Human factors
  - Safety
  - Survivability
  - Vulnerability
  - Supportability (serviceability)
  - Productivity (manufacturability)
  - Reconfigurability (flexibility)
  - Affordability (life-cycle cost)
  - Disposability (retirement/recycling)
  - Environmental feasibility

*Applicable to all levels in the system hierarchical structure and “tailored” to specific program needs.

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**Design Task/Methods**

- Design accomplished through
  - Requirements analysis
  - Quality function deployment
  - Feasibility analysis
  - Operational requirements and maintenance concept
  - Functional analysis
  - Design trade-off studies
  - Simulation and modeling
  - Requirements allocation
  - Reliability and maintainability analyses and predictions
  - Human factors analysis
  - Supportability analysis
  - Safety/hazard analysis
  - Test and evaluation
  - Risk analysis
  - Other supporting analyses
CAD, CAM, CAS, Macro-CAD
Some CAD, CAM, CAS, Macro-CAD Advantages

- Designer can address many different alternatives in a relative short time frame
- Designer is able to simulate, and verify design, for a greater number of configurations
- The ability to incorporate design changes is enhanced, both in terms of the reduced time for accomplishing them and in the accuracy of data presentation
- The quality of design data is improved, both in terms of methods for data presentation and in the reproduction of individual data elements
- The availability of an improved database earlier in the system life cycle facilitates the training of personnel
Analytical Models Usage

- The model should represent the dynamics of the system configuration being evaluated.
- The Model should highlight those factors that are most relevant to the problem at hand.
- The model should be comprehensive by including all relevant factors and be reliable.
- Model design should be simple enough to allow for implementation in problem solving.
- Model design should incorporate provisions for ease of modification or expansion.
Mathematical Models

- Will uncover relationships between the various aspects of a problem that are not apparent in the verbal description.
- Enable a comparison of *many* possible solutions and aids in the selecting the best among them rapidly and efficiently.
- Explain situations that have been left unexplained in the past by indicating cause-and-effect relationships.
- Readily indicate the type of data that should be collected to deal with the problem in a quantitative manner.
- Facilitate the prediction of future events.
- Aid in identifying areas of risk and uncertainty.
A Generic Systems Analysis Process

1. REQUIREMENTS
   - Engineering management
   - Decisions

2. ANALYSIS APPROACH
   - Define the problem
   - Define analysis goals, ground rules, constraints
   - Identify feasible alternatives
   - Define approach to problem resolution

3. EVALUATION CRITERIA
   - Define measures or “figures of merit”
   - Define variables
   - Identify data needs—existing data, estimating, predictions, sources, etc.
   - Identify risks and uncertainty

4. EVALUATION TECHNIQUES
   - Select appropriate techniques—simulation, mathematical/linear/dynamic programming, queuing, accounting, networking, etc.
   - Define modeling requirements (technique application)

5. DATA COLLECTION
   - Use existing data
   - Generate new data through predictions and analyses
   - Acquire actual test data

6. EVALUATION OF ALTERNATIVES
   - Run model (tailored to the individual problem needs)
   - Perform sensitivity and contingency analyses (impact on results based on input variations)

7. Appropriate action

8. ANALYSIS RESULTS
   - Recommendations
   - Confidence levels
   - Trade-offs
   - Break-even points
   - Sensitivities (risks and uncertainty)

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Example of the Application of Models