Topic Outline

• Underpinnings of Systems Engineering
• Requirements: foundation for Systems Engineering work
• Introduction to Systems Engineering design methodologies
• Designing systems for their life cycle
Systems Engineering (SE)

• Interdisciplinary approach enabling the realization of systems that satisfy customer needs throughout their entire life cycles (INCOSE)

• Component fields of knowledge
  – Systems thinking
  – Concurrent engineering
  – Project / program management
  – Total Quality
SE and Traditional Engineering

- Systems engineering
  Promotes top-down, integrated, life-cycle approach to developing a new system
- Traditional engineering disciplines
  Use bottom up approach in designing new systems
System: Linked Parts Array

- Interdependent assemblage of parts interactively working together toward a common objective
- Assemblage of parts *does something*
- Parts affect system and vice versa
- Parts need to be *linked* for system to work
- System organized as *hierarchy* of parts
- System is a subsystem of a higher level system and is itself composed of lower level subsystems
Systems Thinking

A way of thinking about systems and their components emphasizing the relationships among a system's parts rather than the parts themselves
Systems Approach

Definition

• Developing a thorough understanding of the functioning of systems and the ability to see and understand interrelationships of the parts and the whole

• Methodology
  – Decomposition / analysis
  – Integration / optimization
Systems Approach
Methodology

- Decomposition / analysis
  Breaking *whole* down into parts to reveal their *functioning* and *interrelationships*

- Integration / optimization
  Putting parts back together to create an *aligned whole* ensuring they all *work in unison* to achieve system objectives
Systems Approach
Comparison with Analytical Approach

• Traditional Analytical approach
  Focuses on separating, isolating and optimizing individual parts

• Systems approach
  Focuses on analyzing things as a set of interdependent parts, including optimizing the system as a whole
Projects and Programs

• Project
  A unique set of tasks meant to deliver a defined outcome to meet customer needs within an established time frame using a specified resource allocation

• Program
  Linked multiple projects managed in a coordinated way through integrated planning, execution and control
Project Categories Making Up a Program

- Set of *independent* multiple projects
- Subset of *interdependent* projects supporting a single “mega project”
- Systems Engineering programs usually *mega projects*
Systems / Product Lines

Categories

- Repositioned products
- Cost reductions
- Revisions / additions to current products
- New-to-the-world products
- New Products

Newness to Company

Newness to Market
Systems / Product Lines
Role in Business Strategy

- Market Development
- Business Development
- Market Penetration
- Product Development
Systems / Product Lines
Measuring Value

• Derived from *benefit* to customer
  – Savings in *time*
  – Savings in *cost*
  – Improvement in *quality of customer solution*

• Measured against *requirements*
Requirements Categories
Customer Requirements

• Clarify boundaries of system for which customer is willing to pay
• Describes customer’s stated and implied needs in clear [non-technical] terms
• Serve to guide systems requirements
Requirements Categories
System Requirements

- Functional: identify *what* system needs to do to fulfill identified customer requirements
- Performance: state *how well* system needs to perform and *how verified*
- Serve to guide system design
Deriving Requirements
Needs Analysis

Identifying customer’s stated and implied needs, relative importance to the customer, and how customer will measure success
Deriving Requirements
Requirements Analysis

Defining system technical requirements by studying and understanding customer needs and objectives in context of planned customer use.
Deriving Requirements
Process Summary

Diagram:
- Needs Analysis
- Customer Requirements
- System Requirements
- Requirements Analysis

Some Requirements Issues

- Customer has only vague idea of what they need or what their problem entails
- Developer willing to proceed with “vague idea” on assumption “we’ll fill in details as we go”
- Customer keeps changing the requirements
Basic Systems Acquisition Process
Basic Systems Acquisition Process
Requirements Analysis

• Translate customer requirements into a set of requirements defining:
  – What the system must do
  – How well it must perform

• **Outcome**: system specification
  (functional baseline)
Basic Systems Acquisition Process
Functional Analysis and Allocation

• Derive a functional description of system for analysis, synthesis and tradeoff studies
  – *Decompose* to lower level functions
  – *Allocate* system requirements to all functional levels

• *Outcome:* system functional architecture (allocated baseline / design criteria)
Basic Systems Acquisition Process

Design Synthesis

• Transform functional architecture to a physical architecture
  – Verify and integrate physical system elements
  – Select and validate preferred system design

• **Outcome**: validated physical architecture
  (decision database / system baseline)
SE Program Life Cycle VEE Model
Program and System Life Cycles

• Program life cycle
  Applies to all programs and projects, regardless of systems being engineered

• System life cycle
  Can vary considerably based on nature of the system and its environment including its acquisition, utilization and disposal
Program and System Life Cycles
System Life Cycle Cost

[Diagram showing the System Life Cycle with cost curves for System Development Cost, Production & Construction Cost, Operation & Support Cost, and Retirement & Disposal Cost.]
System Life Cycle Design

- Develop a holistic concept for the entire life cycle of a system
- Examples include design for:
  - Producibility and disposability
  - Reliability
  - Maintainability
  - Usability (human factors)
Design for Producibility and Disposability

- System design facilitating ease of manufacture and assembly without harming the environment when the system is retired
- Design for manufacturability (DFM): ease with which product or part can be made
- Design for assembly (DFA): simplifying overall system or subsystem assembly
# Manufacturing Process Traits

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Forming</th>
<th>Deforming</th>
<th>Removing</th>
<th>Joining</th>
<th>Modifying</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Costs</strong></td>
<td>High tooling, low labor</td>
<td>High tooling, low labor</td>
<td>Medium tooling, High labor</td>
<td>Low capacity; high labor</td>
<td>Medium to high capital, low labor</td>
</tr>
<tr>
<td><strong>Product rate</strong></td>
<td>High</td>
<td>High</td>
<td>High (milling); to low (grinding)</td>
<td>Medium (welding) to low (adhesive)</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Part Quality</strong></td>
<td>Medium to low</td>
<td>Medium to Low</td>
<td>Medium to high</td>
<td>Medium to Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Flexibility</strong></td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Medium to high</td>
</tr>
</tbody>
</table>
Basic Producibility Principles

- Simplify design
- Standardize materials and components
- Materials selection:
  - Environmentally acceptable
  - Cost-effective
- Ensure inspectability of system
Design for Disposability
Environmental Design

• *Eliminate* environmentally unfriendly materials where possible
• If elimination not possible, *reduce quantity* of such materials
• Design system so components can be
  – *Reused* (with or without refurbishing)
  – Readily *recycled*
Reliability

• Probability that a system, subsystem or component performs its intended function for a stated *period of time* under *specified operating conditions*

• Inherent characteristic of design

• Expressed as number of failures per unit time during a specified duration (failure rate, $\lambda$)
Reliability
Alternative Measures

- Items replaced when failure occurs:
  Mean time to failure (MTTF)
- Repairable items:
  Mean time between failures (MTBF)
- $MTTF \text{ (or MTBF)} = \frac{1}{\lambda}$
Failure Categories

• Early Life or Functional Failure: failure occurring at start of system utilization

• Useful Life or Reliability failure: failure after an initial period of use

• Wear-out Failure: End of system life cycle
Failure Rate Curve

- Early Life or Functional Failure
- Useful Life or Reliability Failure
- Wear-out Failure

Failure Rate vs. Hours
Some key Design Tools

• Identify and analyze failure risks:
  – FMEA
  – Fault tree analysis

• Quantify and improve:
  – Design of experiments
  – Life testing
  – Accelerated life testing
Maintainability

- System’s ability to be retained in, or restored to a specified state of operation within a given period of time

- *Preventive / scheduled maintenance* reduces risk of failure

- *Corrective / unscheduled maintenance* done in response to failures
Maintainability
Preventive / Corrective Tradeoff

Cost of Maintenance

Cost of Repairs

Cost of Operation
Losses Caused by Failures

Controllable Maintenance Cost

Cost of preventive Maintenance

Level of Maintenance

Low

High

Low

High

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Maintainability

- Maintenance is a result of design
- Maintainability expressed in terms of:
  - Maintenance times
  - Maintenance frequency factors
  - Maintenance cost
Maintainability
Some Design considerations

- Technical manuals or maintenance aids
- Modular design techniques
- Plug-in elements
- Design for replacement at higher levels
- Reduced requirements for special tools
Usability

- Extent to which a system can be utilized by specific users to achieve specified goals with effectiveness, efficiency and satisfaction in a particular environment (ISO 9241)
- System design that complements the way people think and act
- Other terms: human factors, ergonomics, human engineering or user friendly
Design Principles

• Early focus on users and tasks: both operator and maintenance personnel

• Empirical measurement: system testing for learnability and usability

• Iterative design: cyclic process of prototyping, testing, analyzing, and refining
Human Factors Overview

OPERATIONAL & MAINTENANCE REQUIREMENTS

- Functional Analysis & Allocation
  - Operations functions
  - Maintenance functions

- Environmental considerations

- Personnel Factors

- Functions allocated to hardware/software
  - NO
  - Functions allocated to human?

- YES

- Human Factors Analysis

SYSTEM DESIGN & DEVELOPMENT
Environmental Considerations

- Political
- Societal
- Economical
- Ecological
- Technological
Personnel Considerations

- Anthropometric: physical dimensions of human body
- Human Sensory: for example vision and hearing
- Physiological: effects of environmental stresses
- Psychological: aggregate of emotions, traits and behavior patterns related to job performance
Human Factors Design Payoffs

- Improved performance
  - Right tasks performed successfully
  - Reduced training costs
  - Improved morale
  - Reduced maintenance costs

- Fewer accidents
  - Less human error
  - Less equipment damage