Lecture #17

Prof. John W. Sutherland

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A Transition

- Course title: “Service Processes and Systems”
- We have spent a good deal of time talking about the “process”
- We now need to spend some time talking about “systems”
What is a system?

- **Definition of a System**
  - A system is a set of interrelated components which interact with one another in an organized fashion toward a common purpose
    - NASA Systems Engineering Handbook

- **Our interest is “service systems” as opposed to complex product systems**
What is a system?

- The elements of a systems may be quite diverse:
  - People and Organizations
  - Software and Data
  - Equipment and Hardware
  - Facilities and Materials
  - Services and Techniques
Systems

Natural

Technical
  - Aircraft
  - Missile
  - ...

Man made

Technical

Non - Technical
  - Economic system
  - Societal systems
  - ...

M R Shankar
Examples of Systems

- A pen
  - A system for making marks on surfaces
- A bicycle
  - A system for human-powered personal transportation
- A library catalog
  - A system for providing information about the books in a library
- A space shuttle
  - A reusable system for moving people and goods from Earth into orbit
Emergent Properties

- Properties which are associated with the system AS A WHOLE rather than the collection of parts
- Dependent on the properties of the system parts AND the system structure
- Examples
  - Emergent property of a bicycle: a transportation system when parts assembled correctly
  - Emergent property of a cell phone: it is a communication device
Emergent Properties

- A property that surfaces when the parts are put together
- Emergence – unpredictable based on a lower level description
Emergent Properties

- Performance
- Reliability
- Safety
- Security
- Usability

- Some of these are non-functional properties – not relating to any specific functionality of the system
- These properties are often more important than detailed system functionality
Systems and their Environment

- Systems not independent – exist in physical, organizational, & political environment with other systems
- System function may be to change environment, e.g., heating system
- Environment affects function of system, e.g., system may require electrical supply from environment
- Organizational as well as physical environment may be important
System Hierarchies

Town

Street

Building

<table>
<thead>
<tr>
<th>Heating system</th>
<th>Power system</th>
<th>Water system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Security system</td>
<td>Lighting system</td>
<td>Waste system</td>
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</table>

Sommerville 1997
What is Systems Engineering

- SE is an interdisciplinary approach and means to enable realization of successful systems
  - It is very quantitative including tradeoff, optimization, selection, and integration of products from various engineering disciplines
  - Can be considered as a separate engineering discipline
Systems Engineering Heritage

- Water Distribution Systems in Mesopotamia 4000 BC
- Irrigation Systems in Egypt 3300 BC
- Urban Systems such as Athens, Greece 400 BC
- Roman Highway Systems 300 BC
- Water Transportation Systems like Erie Canal 1800s
- Telephone Systems 1877
- Electrical Power Distribution Systems 1880
- Focus of Systems Engineering
  - From Original Need
  - To Final Product
    - The Whole System
    - The Full System Life Cycle

- Focus of Component Engineering
  - On Detailed Design
  - And Implementation

Need
- Operations Concept
- Functional Requirements
- System Architecture
- Allocated Requirements
- Detailed Design
- Implementation
- Test & Verification

Arunski et al. 1999
The “Vee” Model of System Development

User Requirements & Concept of Operations

System Requirements & Architecture

Component Design

Procure, Fabricate, & Assemble Parts

Component Integration & Test

System Integration & Test

System Demonstration & Validation

Systems Engineering Domain

Component Engineering Domain

Arunski et al. 1999

Michigan Tech

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Service Processes & Systems
Dept. of Mechanical Engineering - Engineering Mechanics
Michigan Technological University
Systems Engineering Contributions

- Systems engineering brings together two elements that are not usually present
  - A disciplined focus on the
    - end product/service,
    - its enabling components, and
    - its internal and external operational environment (i.e., a System View)
  - A consistent vision of stakeholders’ expectations independent of daily demands (i.e., the System’s Purpose)
Role of SE in Development

- Integrates Technical Effort Across the Development Project
  - Functional Disciplines
  - Technology Domains
  - Specialty Concerns

Arunski et al. 1999
Building Blocks of SE

- **Math & Physical Sciences**
  - Qualitative modeling
  - Quantitative modeling
  - Physical modeling
  - Theory of Constraints
  - Physical Laws

- **Management Sciences**
  - Economics
  - Organizational Design
  - Business Decision Analysis
  - Operations Research

- **Social Sciences**
  - Multi-disciplinary Teamwork
  - Organizational Behavior
  - Leadership

- **Body of Knowledge**
  - Problem definition
    - Concept of operations
    - System boundaries
    - Objectives hierarchy
    - Originating requirements
  - Concurrent engineering
    - System life cycle phases
    - Integration/Qualification
  - Architectures
    - Functional/Logical
    - Physical/Operational
    - Interface
  - Trades
    - Concept-level
    - Risk management
    - Key performance parameters

*Unique to Systems Engineering* 
Arunski et al. 1999
“Ethical” Considerations

- Achieving balance between inherent conflicts
  - System Functionality and Performance
  - Development Cost and Recurring Cost
  - Development Schedule (Time to Market)
  - Development Risk (Probability of Success)
  - Business Viability and Success

- System Optimization
  - Subsystems often suboptimal to achieve best balance at system level

- Ultimate system purpose must prevail against conflicting considerations
- Long-term considerations (e.g., disposal) may drive technical decisions

- Customer Interface
  - Often must act as “honest broker”
  - Carries burden of educating customer on hard choices
  - Must think ahead to the next customer and next application
  - Must “challenge” all requirements
Components of SE to Remember

- Decompose a complex system into manageable parts or subsystems
- Flow requirements down into each subsystem
- Consider verification of the system and subsystem from the beginning
- Model the system and subsystem performance
- Iterate! As you learn more, revisit your models and assumptions for refinement
- Don’t forget the interfaces between systems
Management Part of SE

- Requirements
- Work breakdown structure
- Scheduling
- Budget and resource planning
- Risk assessment
- Configuration management
- Reviews
Work Breakdown Structure

- **What is a WBS?**
  - A hierarchical breakdown of the work necessary to complete a project. The WBS should be “product” based. Each product should have a person responsible for delivery.

- **Common WBS errors**
  - The WBS describes function and not products
  - Branch points are inconsistent with products and verification
Scheduling

- Start with known milestones
- Consider each component in the WBS
  - Determine who will be responsible
  - Estimate the time required to complete
  - Consider dependencies (order of events)
  - Include subsystem integration and verification
- Don’t forget system testing
- Include a schedule margin to reduce risk
- Evaluate the schedule regularly
- Determine critical path – sequence of activities that will take longest to accomplish
Risk

- Risk should be actively managed

- Risk management components
  - Planning
  - Identification and characterization
  - Analysis
  - Mitigation and tracking
Configuration Management

- How to track changes in documents such as requirements, drawings, schematics, etc.
- Remember – the systems engineering process is iterative
- Methods
  - Assign one group member the responsibility of tracking documents (e.g., the librarian)
  - Can use a numbering system
  - Software is available to help
Words of Advice

- Optimal system – subsystems not necessarily optimal
- “Better” is the enemy of “good enough”
- Goal: meet the system requirements
- Systems engineering is a process. Follow the process to improve your probability of success.