Lecture #17

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A Transition

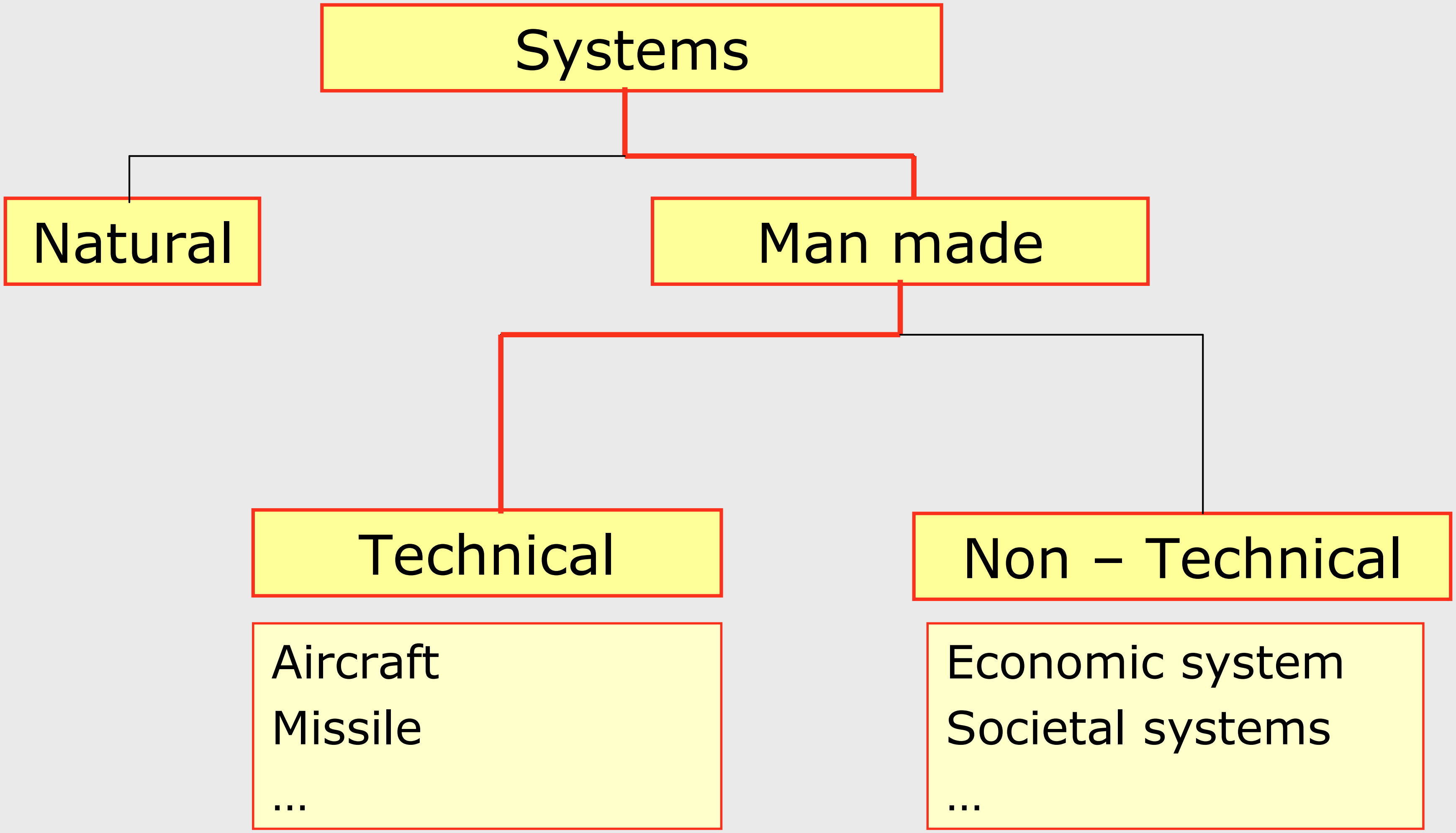
- Course title: “Service Processes and Systems”
- We have spent a good deal of time talking about the “process”
- We now need to spend some time talking about “systems”

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



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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

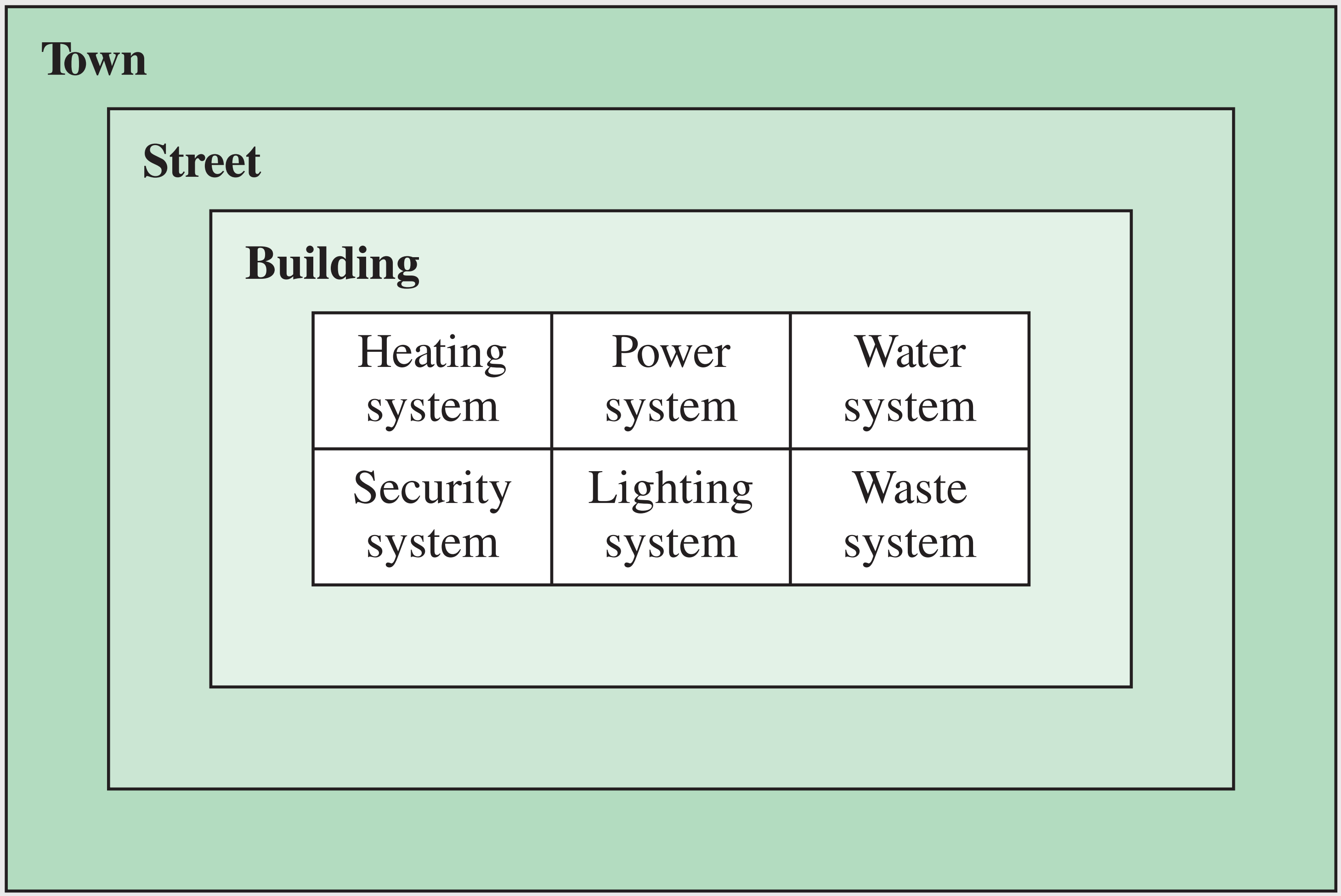
Emergent Properties

- 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



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*

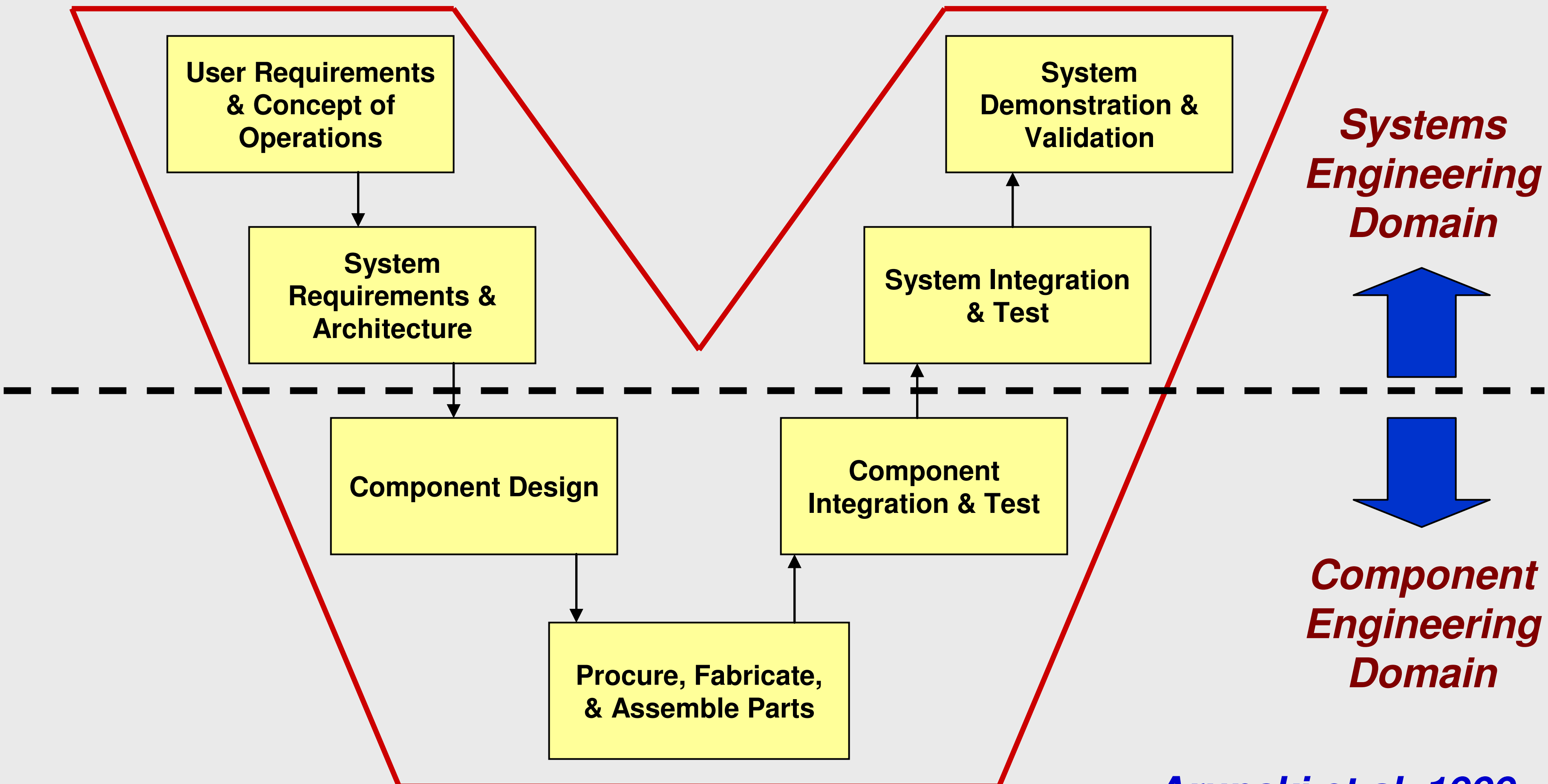
- ***Focus of Systems Engineering***
  - ***From Original Need***
  - ***To Final Product***
    - ***The Whole System***
    - ***The Full System Life Cycle***

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

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

Arunski et al. 1999

The “Vee” Model of System Development



Arunski et al. 1999

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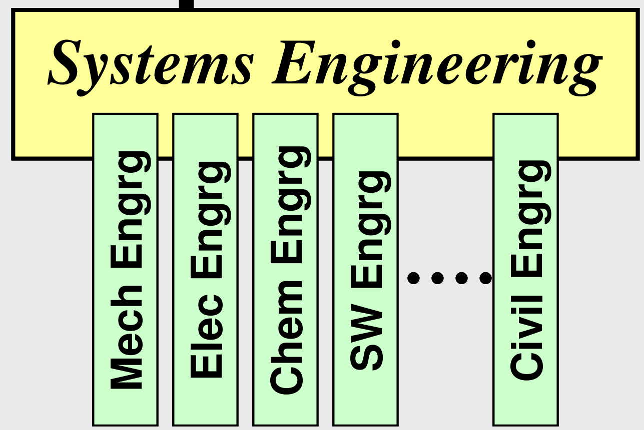
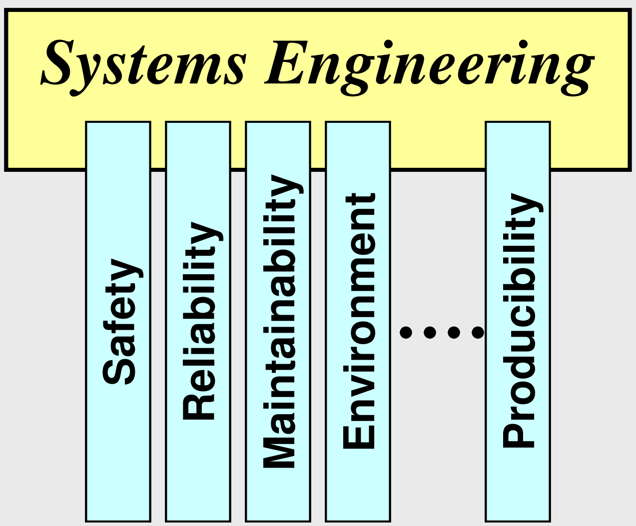
Systems Engineering Contributions

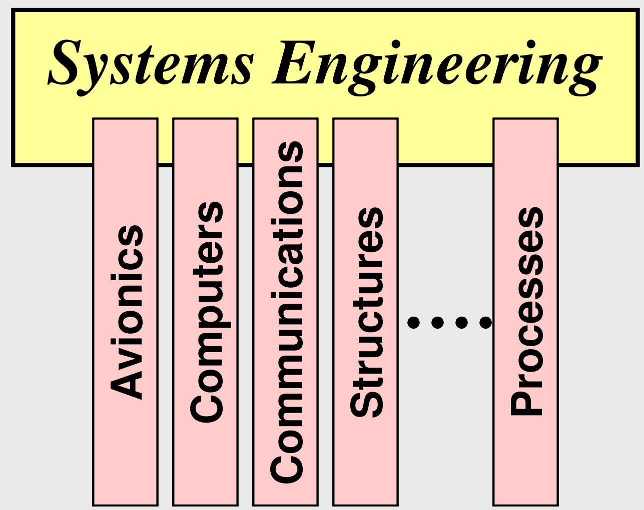
- Systems engineering brings together two elements that are not usually present
  - A disciplined focus on the
    - end product/service,
    - its enabling components, and
    - its internal and external operational environment (i.e., a System View)
  - A consistent vision of stakeholders' expectations 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*

Unique to Systems Engineering

- ***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*

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 projects. 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.