Systems Engineering. Ch.1:
Systems Development
Environment and Process

Systems Engineering

Chapter 1:

Systems Development Environment and Process

Outline

§1. What is Systems Engineering?

- A system is a ***set*** of ***interrelated components*** working ***together*** toward some ***common*** objective
- Guiding the engineering of ***complex*** systems
- Applying scientific principles to practical ends; as the design, construction and operation of efficient and economical structures, equipment, and systems

Difference from traditional engineering disciplines

- Focus on the system as a whole; it emphasizes its total operation and external factors
  - Customer needs, operational environment, interfacing systems, logistics support requirements, operating personnel, etc.
- Leading the concept development
  - Qualitative judgments balancing a variety of incommensurate quantities and utilizing experience, especially when dealing with new technology
- Bridging the traditional engineering disciplines and gaps between specialities
  - Coordinate the design of each individual component to assure that the interactions and interfaces are compatible and mutually supporting

Project management

- Exploratory stage: a new system concept is evolved to meet a recognized need or to exploit a technological opportunity
- A dedicated team to lead and coordinate the activity -> ***project***
- SysEng is an inherent part of project management
  - Setting objectives
  - Guiding execution
  - Evaluating results
  - Prescribing corrective actions

Origins and Basic Factors

- Effects of World War II
  - Rapid growth of technology in mechanics and automation
  - the 1950s and 1960s: distinct discipline
- Advancing technology
  - Opportunities for increasing system capabilities
- Competition
  - Seeking superior solutions
- Specialization
  - Partitioning the system into building blocks corresponding to specific product types
  - Strict management of the interfaces and interactions

Orientation of Technical Professionals

- Figure 1.2 from [Kossiakoff et al., 2011], p.16

Career Development Model

- Figure 1.4 from [Kossiakoff et al., 2011], p.20

Multidisciplinary Knowledge

- System development project is "Tower of Babylon"
- Many specialists in different disciplines
  - Collective efforts to produce a successful new system
- Systems engineers provide linkages that enable disparate groups to function as a team
- Interdisciplinary knowledge is a small fraction of the depth necessary to work in the field

Approximate Calculation

- The ability to carry out "back of the envelop" calculations to obtain a "sanity check" on the results of complex calculation or test
- Intuitively, on the basis of past experience
- Rough estimates to ensure that a gross omission or error has not been committed
- Derivation of an order of magnitude result to serve as a check
- If a check fails then go back to make a careful examination of the assumptions and conditions

Skeptical Positive Thinking

- Skeptical: tempering the traditional optimism of design specialist (regarding to success of a chosen design approach)
- Positive: reaction in the face of failure of a selected technique/approach
  - Healthy skepticism of the conditions under which the unexpected failure occurred
  - Looking for alternative solutions (due to the power of multidisciplinary knowledge)

Life cycle development

- SysEng can be viewed in terms of the depictions of the sequence of processes and methodologies used in the execution of the design
- Many models exist; Figure 2.6 from [Kossiakoff et al., 2011], p.36
- Life cycle is associated with a number of system engineering and project management products or outputs:
  - Context diagrams, problem definition, user needs, scenarios, candidate concepts, traceability, prototype integration, operational tests, …

§2. Structure of Complex Systems

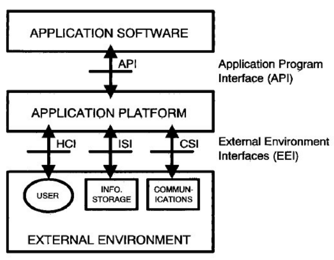
- SysEng knowledge must be sufficient to recognize such factors as program risks, technological performance limits, interfacing requirements
- Trade-off analysis among design alternatives
- Examination of structural hierarchy of modern systems: identifiable types of building blocks that
  - make up the majority of systems
  - Represent the lower working level

Decomposition

- Complex systems have hierarchical structure
  - A number of major elements (subsystems)
  - Then simpler functional elements (components),
  - And so on down to primitive elements (subcomponents, parts, …)
- Hierarchy defines the respective knowledge domains of both the system engineer and the design specialist
- Figure 3.1 from [Kossiakoff et al., 2011], p.45
- Super-systems
  - A complex system can be part of large systems

System Environment

- Everything ***outside*** of the system that ***interacts with*** the system
- Identification and specification in detail all of the ways in which the system and its environment interact
- Accurately reflect the full range of operating conditions



Open system model

System boundaries

- What is part of the system and what is part of the environment?
- Criteria an entity is part of a system
  - Developmental control: developers' sphere of influence
  - Operational control: organization that controls the entity operation in the system
  - Functional allocation: may the systems engineer to allocate functions to the entity?
  - Unity of purpose: can the entity be removed without objection by another entity?

User entity

- Users should be considered external to the system (in majority of cases)
- Developers and even system owner rarely have sufficient control over users to justify the inclusion into the system
- Instead, developers focus on user interface
- In a functional sense, the users may well be considered to be integral parts of the system

Context Diagram

- Displays external entities and their interactions
- Figure 3.2 from [Kossiakoff et al., 2011], p.53
  - The system is a black box
  - External entities
  - Interactions
    - Data
    - Signals
    - Materials
    - Energy
    - Activities

Interfaces and Interactions

- Interfaces: external and internal
- SysEng: management of interfaces
  - Identification and description of interfaces as part of system concept definition
  - Coordination and control of interfaces to maintain system integrity during development, production, and subsequent system enhancements
- Interactions
  - Between two individual elements through their interface
  - Multiple participants

§3. Development process

- Evolution of a particular new system
  - A need is recognized
  - A feasible technical approach is identified
  - Development
  - Introduction to operational use
- A complex effort, referred to as the ***system development process***

Stepwise process

- Typical characteristics
  - Complex effort is required
  - Important user needs to satisfy
  - Several years to complete
  - Made up of many interrelated tasks
  - Several different disciplines are involved
  - New technology is applied
  - Performed by several organizations
  - Specific schedule and budget
- Development must be conducted in a step-by-step manner
- The success of each step is demonstrated
- The basis for the next one is validated before a decision is made to proceed to the next step

System Life Cycle

- Concept development: formulation and definition
  - Needs analysis
  - Concept exploration
  - Concept definition
- Engineering development: validated physical system
  - Advanced development
  - Engineering design
  - Integration and evaluation
- Post-development: evolution
  - Production
  - Operations and support

Concept Development

- Analysis and planning that is necessary to establish
  - The need for a new system,
  - The feasibility of its realization
  - The specific system architecture to best satisfy the needs
- Also the principal objectives include
  - Market analysis for a new system
  - Development of any new technology called for by the selected system concept and validation of its capability to meet the requirements
- SysEng leads this development

Engineering Development

- Transformation of the selected concept into hardware/software solutions:
  - A prototype system satisfying the requirements of performance, reliability, maintainability, and safety
- Build and test of production models
  - The system for economical production and use
  - Demonstration of its operational suitability
- SysEng guides the development

Post-development

- Activities beyond the system development period
- They still require significant support from SysEng,
  - especially when unanticipated problems requiring urgent resolution are encountered
  - Continuing advances in technology often require in-service system upgrading

Evolutionary Characteristics

- Predecessor systems
  - Reusability
- System materialization
  - Descriptions evolve from concepts to reality
  - Documents, diagrams, models, and products all change correspondingly
  - Table 4.1 from [Kossiakoff et al., 2011], p.84
- Participants
  - Key participants can change during development
  - System engineers play a key role throughout all phases

Systems Engineering Method

- Systematic application of the scientific approach to the engineering of a complex system
- Four basic activities
  - Requirements analysis: Problem definition
  - Functional definition: functional analysis, allocation
  - Physical definition: synthesis, physical analysis, allocation
  - Design validation: verification and evaluation

Requirements analysis

Identification of requirements

- Organization and interpretation
  - System model: design choices made and validated in the preceding phases
  - Requirements (specification): design, performance, interface features to be developed on the next phase
  - Specific progress each component must achieve on the next phase
- Clarification, correction, quantification
  - Requirements are often incomplete, inconsistent, vague
  - Interaction with prospective users to gain first-hand understanding of their needs
  - Firm basis from which the nature and location of design changes needed to meet the requirements may be defined

Functional definition

Translation of requirements into functions

- Translation into function and allocation to components
  - Decomposition and allocation of each iterative set of requirements and functions for implementation at the next lower level of system definition
- Trade-off analysis
  - Postulated alternatives are examined
- Functional interactions
  - Definition of the functional and physical interconnection and interfacing of building blocks
  - Modular architectures

Physical definition

Synthesis alternative (physical) implementations

- Alternative components analysis
- Selection of preferred approach
- Interface definition

Design validation

Compliance with requirements, searching undetected errors

- Modeling the system environment
- Tests and Test data analysis

Testing throughout system development

SysEng Method over Life Cycle

- Table 4.3 from [Kossiakoff et al., 2011], p.102

Materials for seminar

- http://en.wikipedia.org/wiki/Systems_engineering
- http://www.sie.arizona.edu/sysengr/whatis/whatis.html
- Systems Engineering Guidebook for ITS. Ver.3 http://www.fhwa.dot.gov/cadiv/segb/
- Online course materials, e.g., http://alison.com/courses/Systems-Engineering