Systems Engineering Essentials (in Aerospace)

March 2, 1998

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Executive Summary

- *"Boeing wants Systems Engineers . . ."*
- Systems Engineering (SE) is not new and integrates all of the issues in engineering
- SE involves a ***life-cycle balanced*** perspective to engineering design and problem solving
- An SE approach is *especially* useful when there is no single "correct" answer
- ***ALL*** successful project team leaders and management employ SE concepts

Overview

- My background
- Review: definition of a system
- Systems Engineering
  - What is it?
  - What isn't it?
  - Why implement it?
- Ten essentials in Systems Engineering
- Boeing wants Systems Engineers. WHY?
- Summary and Conclusions

My Background

- BS Aerospace Engineering, Virginia Tech, 1990
- ME Mechanical & Aerospace Engineering, Manufacturing Systems Engineering, University of Virginia, 1997
- NASA B737 High-Lift Flight Experiment
- NASA Intercenter Systems Analysis Team
  - Conceptual Design and Mission Analysis
  - Technology and Systems Analysis
- I am not the "Swami" of Systems Engineering

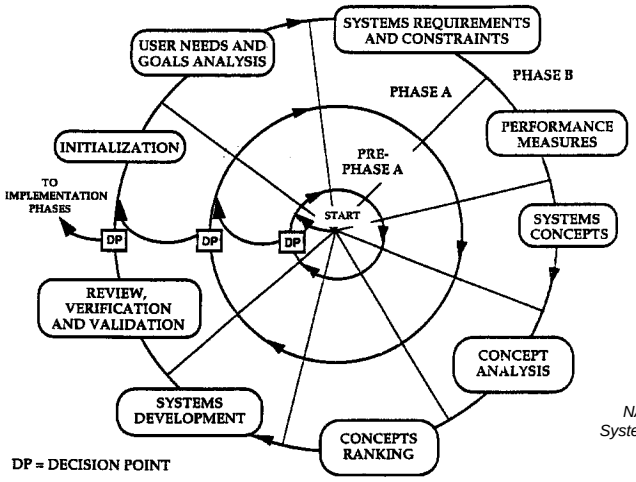
Review: Definition of System

- "*A set of elements so interconnected as to aid in driving toward a **defined** goal*." (Gibson)
- Generalized elements:
  - Environment
  - Sub-systems with related functions or processes
  - Inputs and outputs
- Large-scale systems
  - Typically include a **policy** component ("beyond Pareto")
  - Are high order (large number of sub-systems)
  - Usually complex and possibly unique

Systems Engineering is . . .

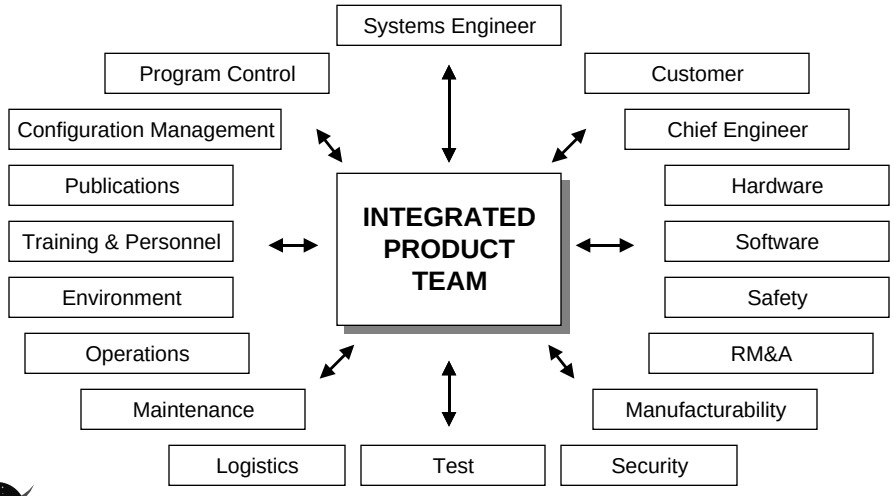
- *An interdisciplinary collaborative approach to derive, evolve, and verify a life-cycle balanced system solution that satisfies customer expectations and meets public acceptability* (IEEE-STD-1220, 1994)
- the absence of stupidity
- i.e. a structured approach to common sense
- not new! And descended from Operations Research

A Systems Engineering Conceptualization



Source: NASA Langley Systems Engineering Handbook

Concurrent Engineering = SE

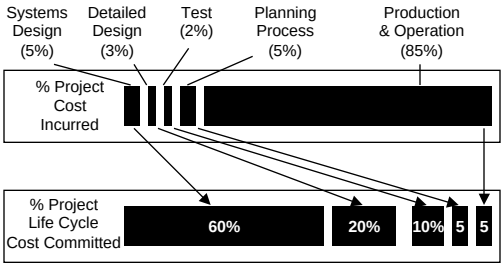


Systems Engineering is not . . .

- Simply project management
- Simply trade studies
- Simply checking off the boxes in a project plan
- Simply a “standardized” process or procedure

Why Systems Engineering?

- “Life Cycle Mentality”
- Real world metrics
  - Faster
  - Better
  - Cheaper
- “Systems Thinkers”
  - Beyond “multidisciplinary”
  - Σ(Mobility of Knowledge * Experimentation) = 1/Ω(Innovation)
  - Preplanned improvements and flexibility



Source: data from Anderson Consulting, January 1993

Ten Essentials in Systems Engineering

(Gibson, J., *A Systems Analyst's Decalog*, unpublished, July 1991)

- There is always a customer
- The customer does not understand the problem
- The original problem statement is too specific
- The "Metric" concept is complex
- You are the analyst/engineer: not the decision maker
- Meet the time deadline and the cost budget
- Take a goal-centered, not a technology-centered or chronological approach
- Take care of bystanders (or non-users) too
- The universal computer simulation is a fantasy
- Role confusion often exists in decision making

There is Always a Customer

- Someone requires a real solution to a real problem
- Meaningful, detailed requirements
- Level of complexity necessary?
- Provision for feedback
  - Reality check
  - Prevent the engineer from becoming too subjective and taking the easy way out

The Customer Does Not Understand the Problem

- ". . . And thus the engineer should work with the customer to help him gain a proper understanding of the properly defined problem and to select the best solution."

- ***Ask*** the customer questions to verify the problem and the underlying system goals
- Beware of hidden agendas
- The customer is not always the decision maker
- The customer's past solutions may be a "trap"
- Make use of "*Active Listening*"

The Original Problem Statement is Too Specific

- i.e. treat the illness not the symptoms
- "Contextual Integrity"
- Policy-laden problems
  - No rigorous mathematical solution ("one answer")
  - Generalizing the problem and following a top-down approach reduces the likelihood for error
- Issues with generalizing the problem
  - Customer will think you are avoiding the problem
  - Immediate generalization "looks" expensive

The Customer Does Not Understand the "Metric" Concept

- Problem → goals → metrics
- Analysis metrics
  - Measure system effectiveness in achieving customer goals
  - MUST be agreed upon with the customer
- Explicit and implicit optimization
  - Selecting the optimum solution eliminates the need to examine all other possible configurations
  - It is difficult or impossible for the customer to visualize the impact of a particular metric on a complex system
  - *Policy makers in the "real word" regularly produce recommendations that, in principle, cannot be measured*

You are the Engineer: Not the Decision Maker

- Your role:
  - The engineer must take care of the customer
  - The engineer isn't there to get the customer fired
  - Save the customer's job
- Your means:
  - Prepare the customer
  - Prepare solution**s** to the customer's problem
  - Use an approach by which the customer selects from among your solutions to his problem

Meet the Time Deadline and the Cost Budget

- Engineers desire more and more time to do more and more analysis
- Focus on the real problem. Don't tinker.
- Redefining the problem is not a solution
- DO NOT be *too* optimistic in estimates
  - Eat the loss. Get demoted.
  - Go bankrupt. Lose your job.
- A design (or study) is never really finished

Goal-Centered vs. Technology-Centered or Chronological Approaches

- Do you start at the beginning or the end?
- Chronological or Technological approach
  - Starts at the beginning
  - Produces numbers, designs, reports, and dead ends
  - Tends to produce an artificially narrow options field
  - May result in the exclusion of superior solutions
- Goal-centered approach
  - Starts at the end. Output determines input.
  - Often seems to be "wasting time" to many engineers
  - Seeks to generate options and compare using trade studies

Take Care of Bystanders Too

- "Beggar thy neighbor". Uh-uh!
- Better, more competitive design philosophy: *leave the non-user better off than before*
- DO NOT project either your or the customer's value system upon non-users
  - Tobacco manufacturers
  - SST
  - Skylab
- BUT be reasonable, i.e. Cassini, HSCT, ISS

The Universal Computer Simulation is a Fantasy

- Can't get more out of a computer than you put into it
- Computer simulations = mathematical relationships
  - Solutions of a mathematical equation are implied by the mathematical relationship itself
  - You don't know all of the solutions when you write the equation
- Computer simulations = "cheap", fast experimentation
- The "curse of dimensionality"
  - . . . just one more design variable . . .
- "Virtual" design is (will be) no different

Role Confusion Often Exists in Decision Making

- The Customer
  - the person or group with whom the engineer or analyst interacts during goal definition
- Stakeholders
  - are all those affected by the system
- Sponsors
  - pay the bills
  - often the decision maker, may or may not be the customer
- The Decision Maker
  - chooses from among the options
  - must select the particular system metrics

Boeing Wants Systems Engineers WHY?

- Not really
- Boeing wants engineers who *think in terms of systems:*
  - and can understand the system's interactions with their job, task, or problem: big-picture mentality
  - and can communicate to supervisors and colleagues the system-level issues inherent within their job, task, or problem
  - and can communicate with customers, partners, and vendors
- Cost and quality are becoming commodities
- *Development-cycle efficiency, customer responsiveness, and service after delivery are the "new" battlefields for competitive advantage*

Summary and Conclusions

- There often is no single solution to a customer's problem
- Systems engineering is an approach to effective problem solving
- Systems engineering uses a life-cycle balanced perspective
- Systems engineering is basically the application of common sense
- SE techniques are employed by successful project leaders and managers