

Systems Engineering Essentials (in Aerospace)

March 2, 1998

Matt Sexstone
Aerospace Engineer
NASA Langley Research Center

currently a graduate student at the University of Virginia



NASA Intercenter Systems Analysis Team

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



NASA Intercenter Systems Analysis Team

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



NASA Intercenter Systems Analysis Team

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



NASA Intercenter Systems Analysis Team

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



NASA Intercenter Systems Analysis Team

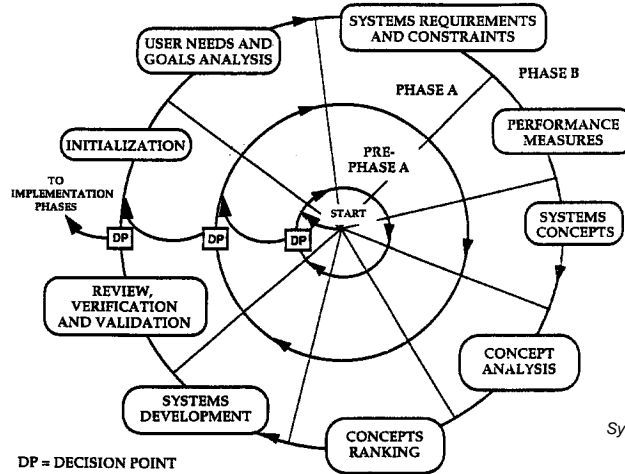
Systems Engineering is . . .

- *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



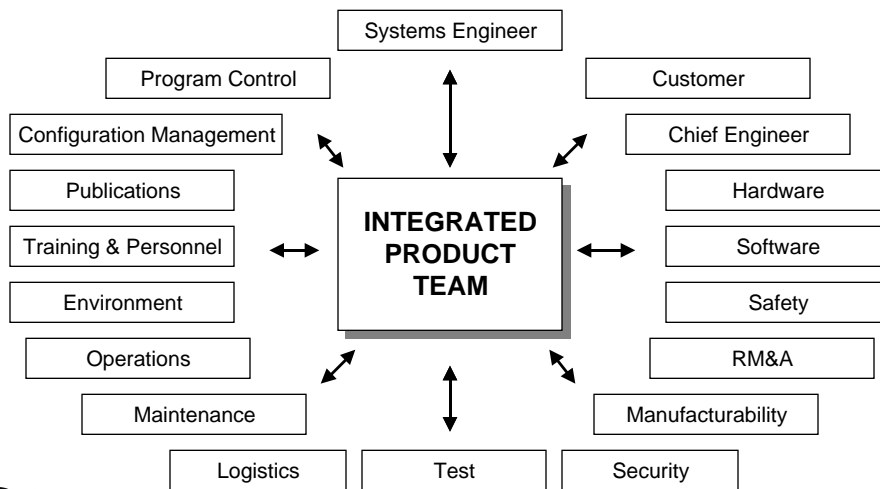
NASA Intercenter Systems Analysis Team

A Systems Engineering Conceptualization



NASA Intercenter Systems Analysis Team

Concurrent Engineering = SE



NASA Intercenter Systems Analysis Team

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



NASA Intercenter Systems Analysis Team

Why Systems Engineering?

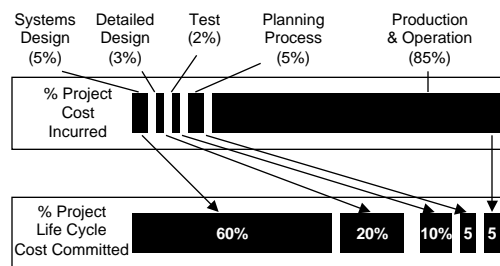
- “Life Cycle Mentality”

- Real world metrics

- Faster
- Better
- Cheaper

- “Systems Thinkers”

- Beyond “multidisciplinary”
- $(\text{Mobility of Knowledge} * \text{Experimentation}) = 1 / (\text{Innovation})$
- Preplanned improvements and flexibility



Source: data from Anderson Consulting, January 1993



NASA Intercenter Systems Analysis Team

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



NASA Intercenter Systems Analysis Team

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



NASA Intercenter Systems Analysis Team

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*”



NASA Intercenter Systems Analysis Team

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



NASA Intercenter Systems Analysis Team

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 world” regularly produce recommendations that, in principle, cannot be measured*



NASA Intercenter Systems Analysis Team

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 solutions to the customer's problem
 - Use an approach by which the customer selects from among your solutions to his problem



NASA Intercenter Systems Analysis Team

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



NASA Intercenter Systems Analysis Team

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



NASA Intercenter Systems Analysis Team

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



NASA Intercenter Systems Analysis Team

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



NASA Intercenter Systems Analysis Team

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



NASA Intercenter Systems Analysis Team

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*



NASA Intercenter Systems Analysis Team

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

