ESD.33 -- Systems Engineering

# Session #1
# **Course Introduction**
# **What is Systems Engineering?**

Dan Frey

Don Clausing

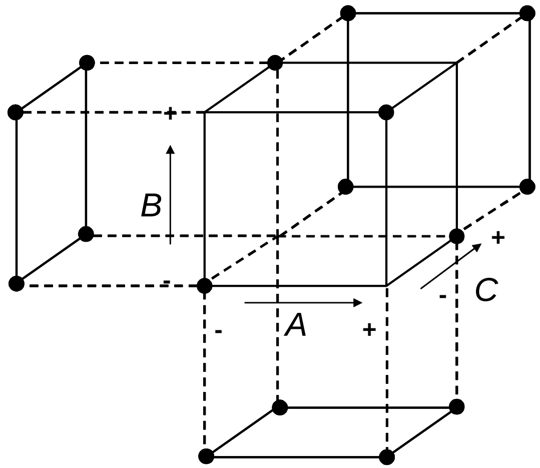
Pat Hale

# Plan For the Session

- Introduce the Instructors
- Outline the Subject and Policies
- Discuss Assignment #1
- What is Systems Engineering?

# Dan Frey

- Research on
  - Product development
  - Statistical methods in engineering
  - Robust design
- Formerly a Naval Officer
- Like many of you, raising kids



# Don Clausing

- Ph. D. at Cal Tech
- ~30 years industry experience
  - Ingersoll-Rand
  - US Steel
  - Xerox
- MIT faculty member
- Author of
  - Total Quality Development
  - Effective Innovation

# Pat Hale

- Retired Naval Officer (Submariner)
- Many years of industry experience
  - Draper Labs
- Consulting in Design for Six Sigma

# Plan For the Session

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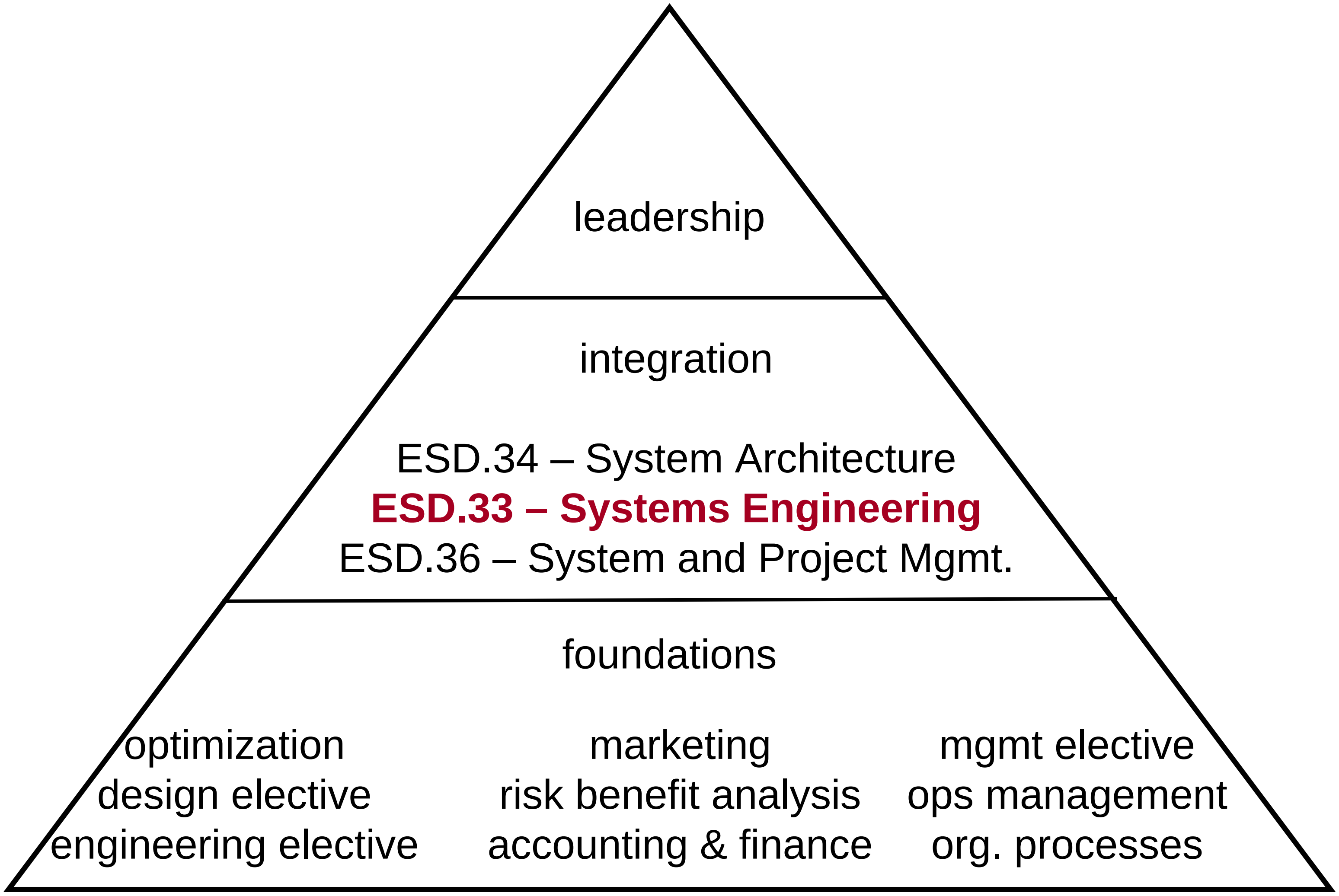
# SDM Program


leadership
integration
ESD.34 – System Architecture
**ESD.33 – Systems Engineering**
ESD.36 – System and Project Mgmt.
foundations
optimization
design elective
engineering elective
marketing
risk benefit analysis
accounting & finance
mgmt elective
ops management
org. processes

# SDM Core Courses
## A Simple View of their Relationship

- **System Architecture (ESD.34)** is about the ARTIFACTS themselves
  - Concept, form, function, decomposition …
- **Systems Engineering (ESD.33)** is about the PROCESSES that enable successful implementation of the architecture
  - QFD, Pugh Concept Selection, Robust Design, …
- **System Project Management (ESD.36)** is about MANAGING TASKS to best utilize resources in the systems engineering process
  - CPM, DSM, System Dynamics …

# ESD.34 - System Architecture Learning Objectives

- Be able to structure and lead the early, conceptual PDP phase
- Discuss systems, systems thinking, products, the PDP and the role of the architect
- Critique and create architecture, and deliver the deliverables
- Execute the role of the architect
- Critically evaluate current modes of architecture

# ESD.33 – Systems Engineering Learning Objectives

After taking this subject you should be able to:

- Develop a systems engineering plan for a project
- Judge the applicability of any proposed process, strategy, or methodology for systems engineering
- Apply the most essential systems engineering tools to realistic problems
- Recognize the value and limitations of modeling and simulation
- Formulate an effective plan for gathering and using data
- Determine the effects of manufacture, maintenance, and disposal on system cost and value

# ESD.36 System & Project Management Learning Objectives

- Introduce advanced methods and tools of Project Management in a product /system development context
  - Probabilistic CPM/PERT
  - Design Structure Matrix
  - System Dynamics
  - Risk Management
  - Earned Value Tracking
- Understand how methods work (strengths, limitations)
  - Industry Examples
  - Case Studies, Strategic Issues

| Date | | Subject | Reading | HW Out | HW Due |
|---|---|---|---|---|---|
| T 8 JUN | | Course Introduction<br>What is Systems Engineering? | Subject Information and Policies.pdf<br>Argyris_Teaching Smart People How to Learn.pdf<br>Schön_The Reflective Practitioner.pdf | #1 | |
| R 10 JUN | Frameworks | INCOSE Model of Systems Engineering<br>RCI model of Systems Engineering | INCOSE Systems Engineering Handbook ch 2.pdf<br>INCOSE Systems Engineering Handbook ch 4.pdf<br>Clausing_RCI Systems Engineering Process.ppt<br>Clausing_Commercial Product Development.pdf | #2 | #1 |
| T 15 JUN | | Lean Thinking<br>Set Based Design | Womak_Lean Thinking Introduction.pdf<br>Stanke_Murman_Lifecycle Value in Aerospace.pdf<br>Ward_The Second Toyota Paradox.pdf | | |
| R 17 JUN | | Axiomatic Design<br>Decision Based Design | Suh_Axiomatic Design Theory for Systems.pdf<br>Frey_Cognition and Complexity.pdf<br>Hazelrigg_Axiomatic Engineering Design.pdf<br>Gigerenzer_Bounding Rationality to the World.pdf | | #2 |
| T 22 JUN | | **Examination #1** | Brooks_No Silver Bullet.pdf | #3 | |
| R 24 JUN | Tools | Quality Function Deployment | Hauser_Clausing_House of Quality.pdf<br>Griffin_Evaluating QFD.pdf | | |
| T 29 JUN | | Pugh concept selection | Pugh_Total Design ch 4.pdf | #4 | #3 |
| R 1 JUL | | Tools for Innovation (TRIZ, etc.) | Clausing_Effective Inovation.pdf<br>Jugulum_Frey_Robustness Invention.pdf | | |
| T 6 JUL | | Functional modeling<br>Object Oriented Modeling | TBD<br>TBD | #5 | #4 |
| R 8 JUL | | Physics-based modeling | Senin_Wallace_Distributed Modeling.pdf<br>Hazelrigg_Role and Use of Models.pdf | | |
| T 13 JUL | | Error Budgeting & Critical Parameter Mgmt. | Frey_Error Budgeting.pdf<br>Crevelling | #6 | #5 |
| R 15 JUL | | Design of Experiments | Thomke_Enlightened Experimentation.pdf<br>Box_Statistics as a Catalyst p1.pdf<br>Box_Statistics as a Catalyst p2.pdf<br>Frey_One Factor at a Time.pdf | | |
| T 20 JUL | | Robust Design | Taguchi_Clausing_Robust Quality.pdf<br>Ulrich_Eppinger_Product Design and Dev ch13.pdf | | #6 |
| R 22 JUL | | Design for Manufacturability | Boothroyd_Dewhurst_TBD.pdf<br>Ishii_TBD.pdf | | |
| T 27 JUL | | **Examination #2** | | | |
| R 29 JUL | Case Studies | Aircraft Engines (GE)<br>Automobiles | Davis_TBD.pdf | #7 | |
| T 3 AUG | | Work on Aircraft Engines Assignment<br>Project Oxygen | Steele_TBD.pdf | | |
| R 5 AUG | | NORAD Command and Control (Mitre) | Folk_TBD.pdf | #8 | #7 |
| T 10 AUG | | Tactical Tomahawk | Cummings_TBD.pdf | | |
| R 12 AUG | | Course Summary / Feedback | | | #8 |

# The Course Website

- Provides access to:
  - Required reading material
  - Syllabus
  - Policies
  - Class notes
  - Homework assignments
  - Forums
- All written homework is to be submitted through this site (as a single MS Word document)

# Course Materials

Last Year

- textbook

  Blanchard, Benjamin S., and Wolter J. Fabrycky. *Systems Engineering And Analysis*. 3rd ed.
- course pack

This year

- NO textbook
- NO coursepack
- files on the web site
- mostly pdf format
- many journal articles
- some book chapters

# Subject Info and Policies

- Reading – please prepare for class
- Class sessions
  - T R 8:30-10:30
  - Notes posted ½ hour prior to the session
- Homework assignments
  - Collaboration encouraged
  - Acknowledge all help received
  - One letter grade per day late
- Two Exams
  - During class time
  - Individual work

Software needed!

# Grading Allocation

| | |
|---|---|
| Homework assignments<br>(8 of them at 5% each) | 40% |
| Exam #1<br>Exam #2 | 10%<br>30% |
| Class participation | 10% |

# Handing in Homework

- Please submit homework through Sloanspace before the class session begins
- Please submit as a single MS Word Document using the following naming convention
  - SpellerTom_HW2.doc
- One letter grade is lost per day late
- In the case of unusual circumstances or *unavoidable* conflicts, please contact Dan Frey to discuss the details and explore alternatives

# Grading Interpretation

- A  - Exceptionally good performance, demonstrating a *superior* understanding of the subject matter, a foundation of extensive knowledge, and a skillful use of concepts and/or materials.
- B  - Good performance, demonstrating capacity to use the appropriate concepts, a *good* understanding of the subject matter, and an ability to handle the problems and materials encountered in the subject.
- C  - Adequate performance, demonstrating an *adequate* understanding of the subject matter, an ability to handle relatively simple problems, and adequate preparation for moving on to more advanced work in the field.

# Time Commitment and Expectations

- ESD.33 is a 12 unit subject (3-0-9)
- The units correspond to the time that an adequately prepared student with good study habits is expected to spend in a normal week
- However, the summer term is compressed from a regular academic year term as there are 10 weeks as compared to 14 during a regular term.
- Thus, the weekly time commitment is 16.8 hrs.
- The out of class time will roughly be split between reading assignments and homework.

# Plan For the Session

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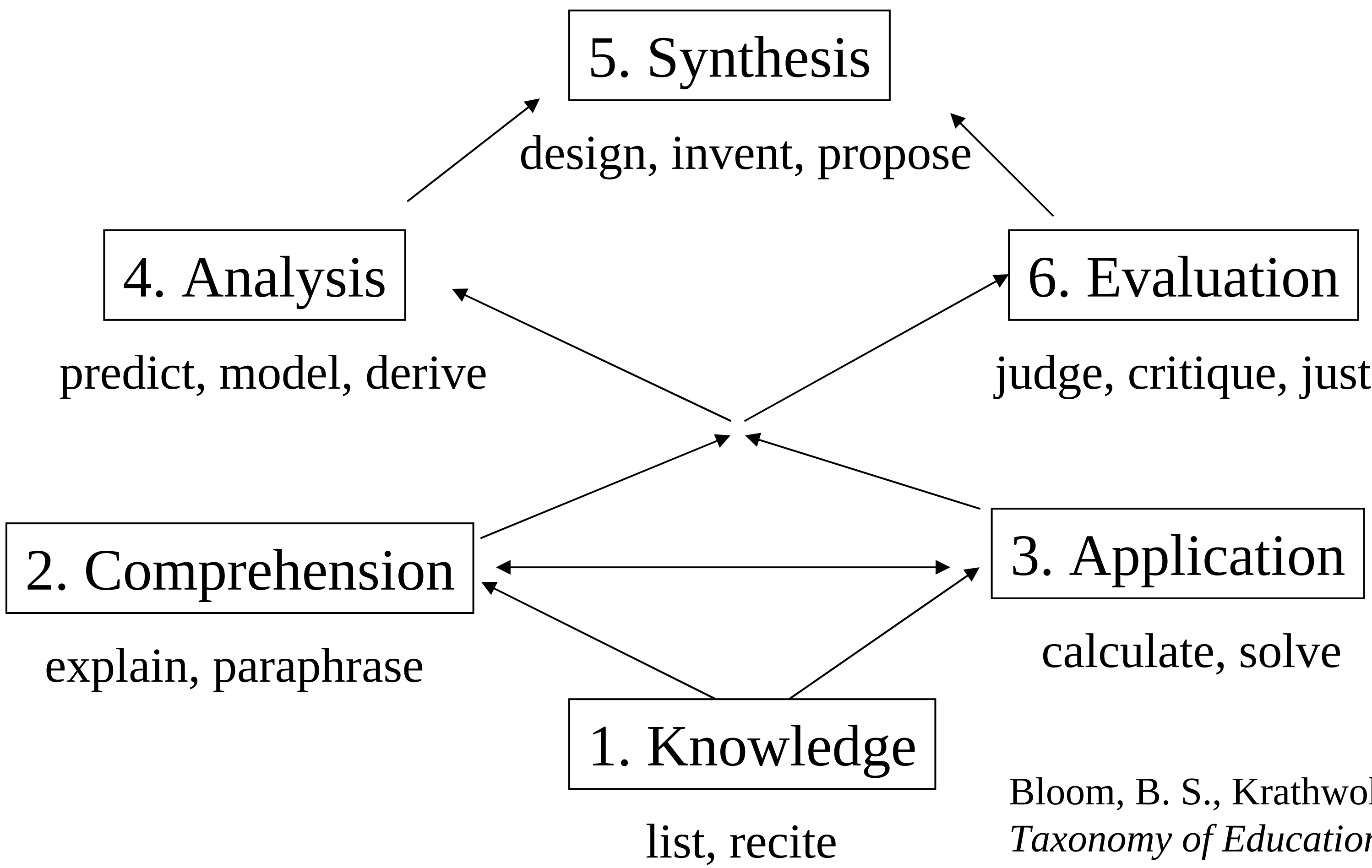
# Assignment #1
# **Learning**

- Due: Thursday 6/10 at 8:30AM
- Approximately 3 pages
- 5% of final grade
- Describe your objectives for the course
- Amplify or challenge 1 point from each of
  - Chris Argyris “Teaching Smart People How to Learn”
  - Donald Schön “The Reflective Practitioner” (notes)
- Write about the conditions conducive to meeting your objectives

# Bloom's Taxonomy of Educational Objectives




Bloom, B. S., Krathwohl, D. R. (1984) *Taxonomy of Educational Objectives*, New York: Addison Wesley.

# Writing Good Learning Objective Statements

- Write objectives at topic or module level
- Identify what the *students should be able to do* (use verbs like calculate, explain, justify)
- Make objectives *clear* and *specific*

  (avoid verbs like know, understand, learn)
- Balance objectives among Bloom's levels
- Revise notes and tests on the basis of objectives

Gronlund, N.E., (1994) *How to write and use instructional objectives.* New York: Macmillan

# Teaching Smart People How to Learn

- “Single Loop Learning” = perfecting your conception
- “Double Loop Learning” = changing your conception
- Smart people are great at single loop learning
- But change in conceptions often comes through failure and smart people aren’t used to failure

# Teaching Smart People How to Learn

| Governing Variables | Action Strategies | Consequences |
|---|---|---|
| • Control the purpose of the meeting or encounter<br>• Maximize winning<br>• Suppress negative feelings<br>• Be rational | • Advocate your position in order to be in control<br>• Save face (yours and others) | • Miscommunication<br>• Self fulfilling prophesies<br>• Self-sealing<br>• Escalating error |

**FIGURE 1**
**Model I Theory-in-Use**

| Governing Variables | Action Strategies | Consequences |
|---|---|---|
| • Valid (validatable) information<br>• Free and informed choices<br>• Internal commitment to choice | • Advocate your position and combine with inquiry and public testing<br>• Minimize face saving behaviors | • Fuller communication<br>• Double loop learning<br>• Solving problems |

**FIGURE 2**
**Model II Theory-in-Use**

# The Reflective Practitioner

- Donald Schön studied the learning process of engineers, managers, architects, and psychotherapists
- Competent practitioners usually know more than they can say (tacit knowledge)
- When someone reflects in action, he becomes a researcher in the practice context
- A practitioner’s reflection can serve as s corrective to over-learning

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# Engineering

The process of devising a system, component, or process to meet desired needs.  It is a decision-making process (often iterative) in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective

– Accreditation Board for Engineering and Technology

# The Earliest Engineering?

Stone tools >>1,000,000 BC

Fire >500,000 BC

Spears circa 400,000 BC

Sewing circa 23,000 BC

Spear thrower 14,000 BC

Domestication of sheep 9,000 BC

Permanent settlement and irrigation 7,000 BC

Copper circa 6,000 BC

Division of labor 5,000 BC

# Systems Engineering

## INCOSE

International Council on Systems Engineering

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

- Operations
- Performance
- Test
- Manufacturing
- Cost
- Schedule
- Training
- Support
- Disposal

# Systems Engineering

## INCOSE

International Council on Systems Engineering

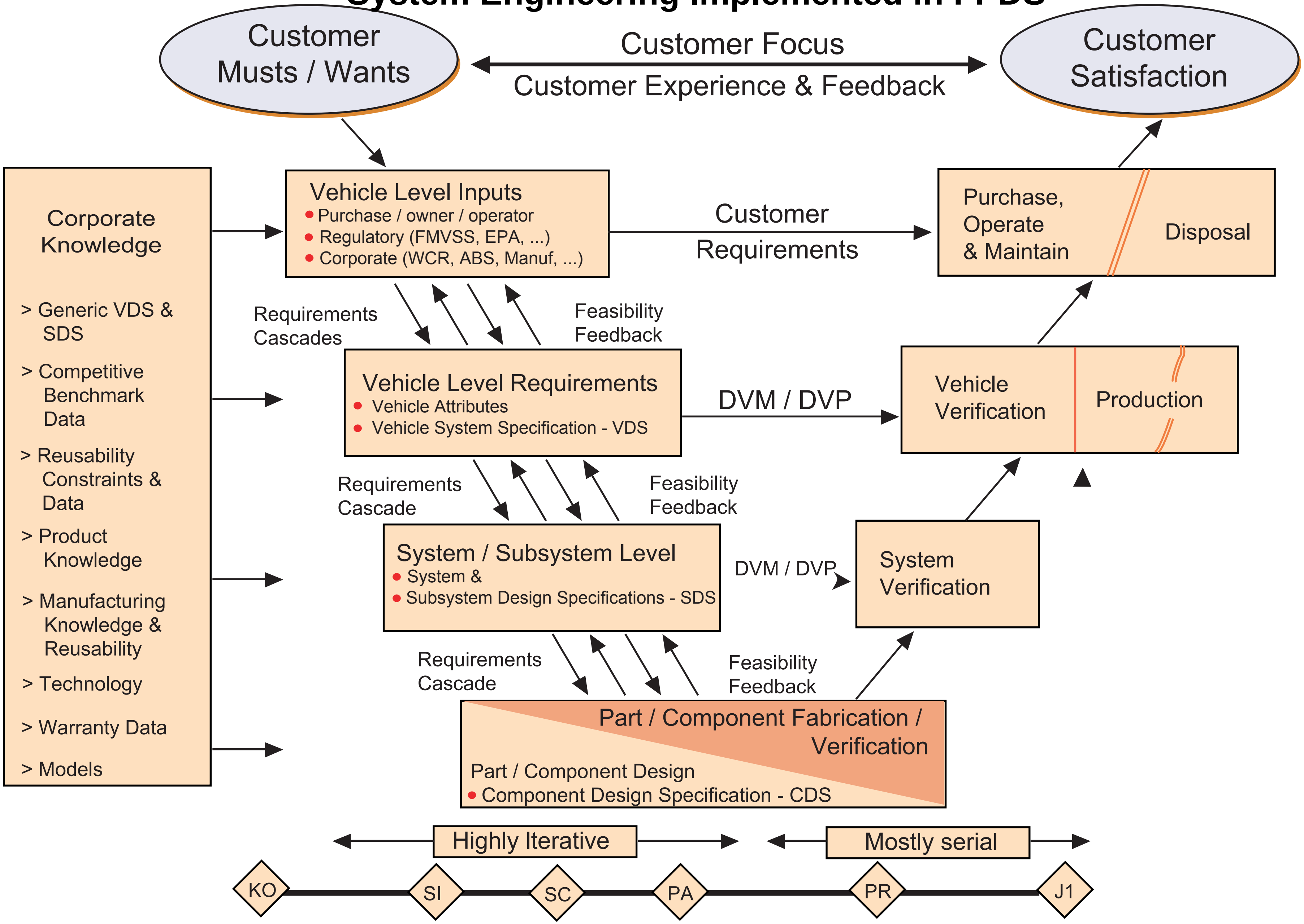
- Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation.

- Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

# Discussion Point

- What distinguishes **Systems Engineering** from **Engineering**?

# System Engineering Implemented in FPDS




**Adapted from Ford Motor Company.**

# The Great Pyramid

- >10,000 people coordinated
- ~30 years of effort
- Did the design and construction of the great pyramid entail systems engineering?

# Discussion Point

- Did the design of the CFM56 jet engine entail a systems engineering function?
- Did the design of Whittle’s jet engine entail a systems engineering function?

# The Machine Age

- Characterized by reductionism
- Ancient roots
  - Aristotle (*Physics*)
  - Archimedes
- Renaissance
- Industrial revolution(s)
  - F. W. Taylor
  - “Scientific Management”
  - Gabor, Andrea. “The Geniuses of Modern Business - Their Lives, Times, and Ideas.” In *The Capitalist Philosophers*.

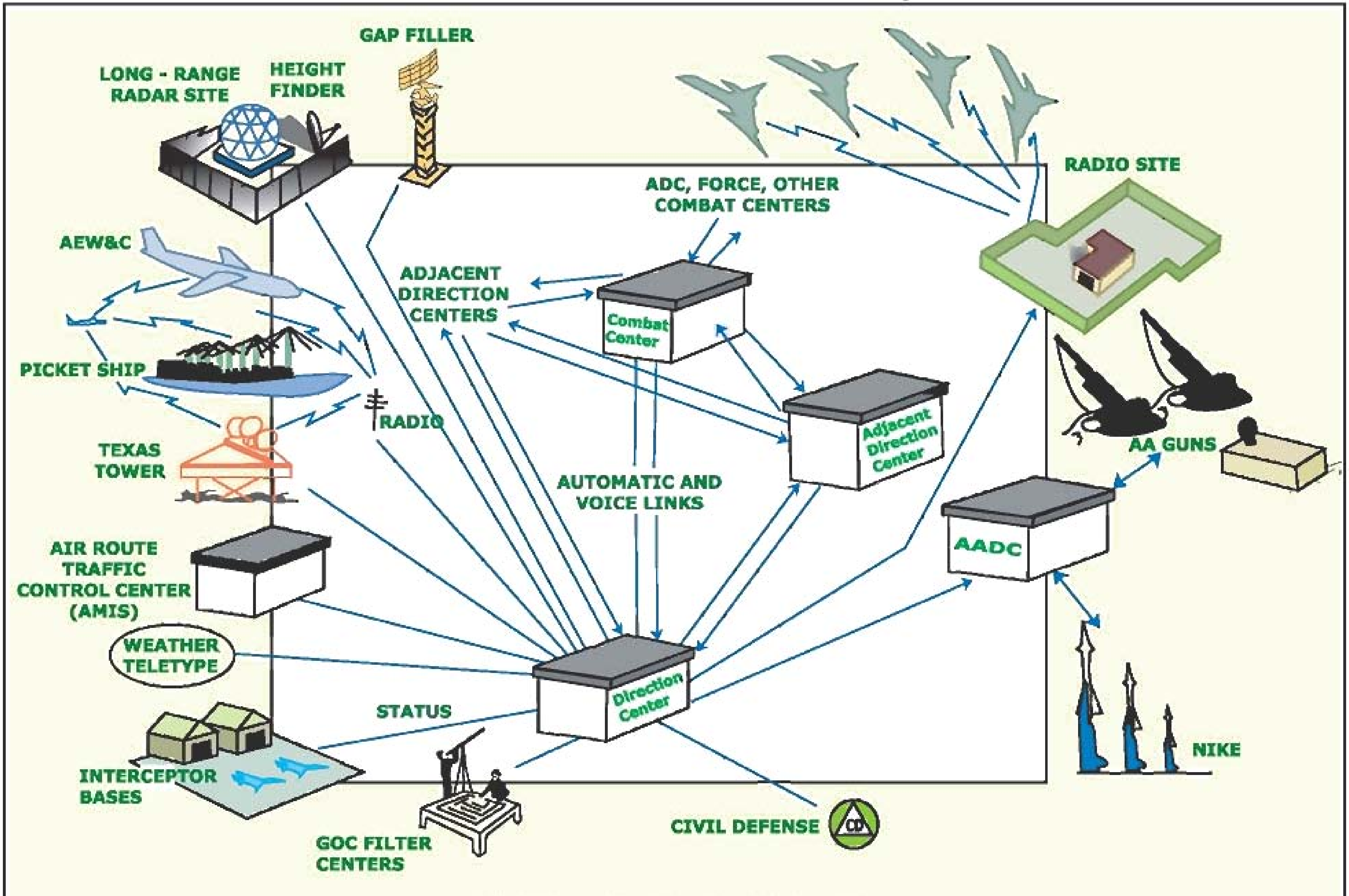
# Discussion Points

- What aspects of systems engineering were practiced pre-WWII?
- Which pre-WWII engineers exhibited systems engineering talents?

# Transition to the Systems Age

- Beginning ~ 1940 (according to Blanchard & Fabrycky)
- *Rescuing Prometheus*
- Thomas P. Hughes, Prof. of History and Sociology of Technology, U. of Penn.
- Tells the story of four major projects
  - SAGE
  - Atlas
  - CA/T
  - ARPANET

# The SAGE Air Defense System




Adapted from MITRE Corporation.

# Key Aspects of SAGE

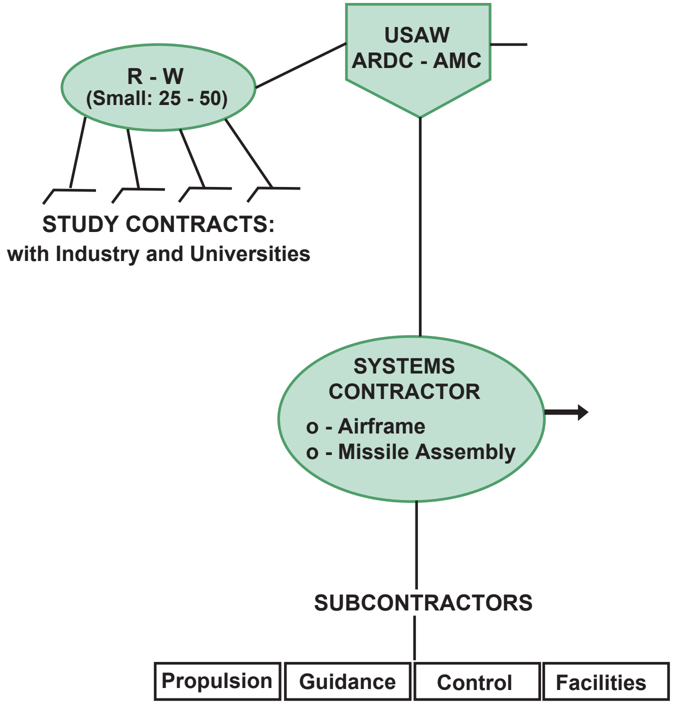
- First project to use computers for info processing and process control
- Engineers play a key management role
- Military / Industrial / University Complex
  - MIT Lincoln Labs
  - MITRE Corporation
- Criticized for its technical inadequacies

# The Atlas Project

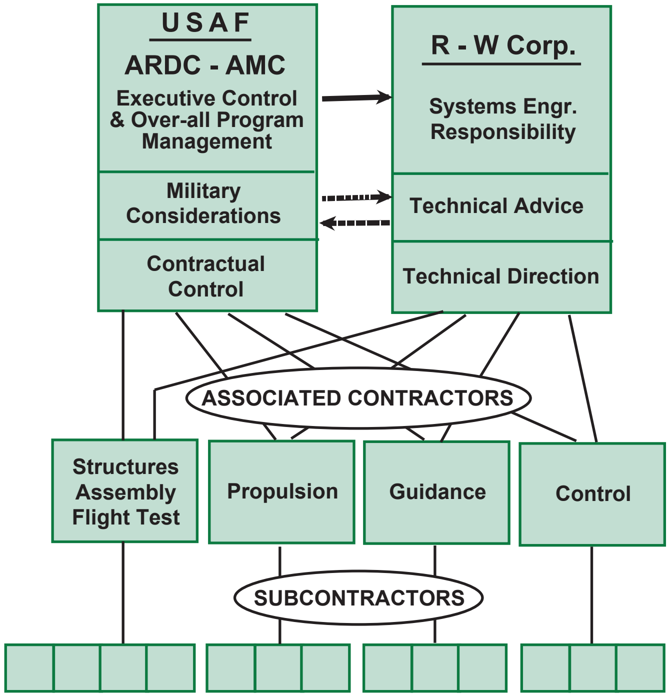
- Produced the first ICBM
- 18,000 scientists and engineers
- 17 contractors
- 200 subcontractors
- 200,000 suppliers
- Coordinated by the Ramo Woodridge Corporation

# Key Aspects of the Atlas Project

- Firmly established the "Systems Engineering" approach to management
- Identified key challenges early (re-entry)




Prime Contractor Approach.




Systems Engineering Approach.

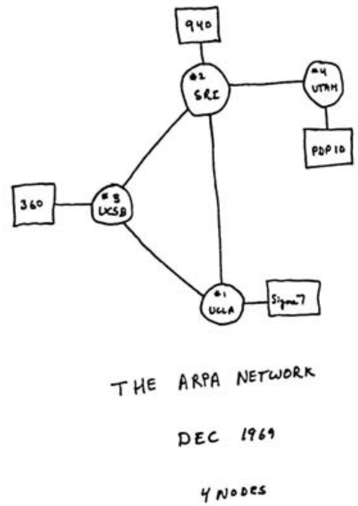
# Boston’s Central Artery Tunnel

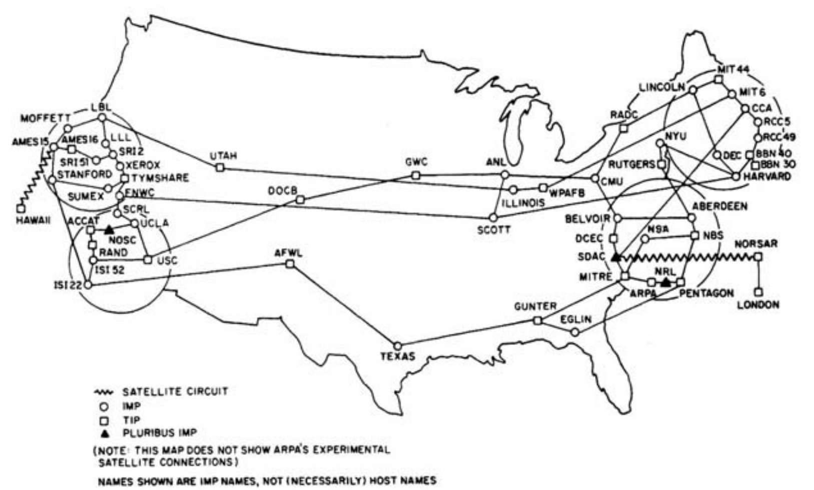
- “The largest, most complex, and technically challenging highway project…”
  - www.bigdig.com/
- >7 Miles of tunnels
- Projected to cost $14.6B
- 87% Complete

# Key Aspects of the CA/T

- Greater “messy complexity” than either SAGE or Atlas (T. Hughes)
- Bechtel / Parsons Brinkerhoff coordinates
- ~1/3 of budget spent on remediation
- Highly publicized mistakes
  - Voids in concrete of Zakim Bridge
  - Planning maps missing the Fleet Center
  - "Based on anecdotal evidence, I believe that there is a genuine potential for monetary recovery. " - MA State Inspector General
- How was the CA/T project similar to/different from from the building of the Great Pyramid?
- Is the CA/T project successful so far?

# ARPANET




- A prime example of scalable architecture
- New trends in management of big projects
  - Flatter - Less centralized - Meritocratic
- Do these trends work for other systems?

# Discussion Points

- Do the systems engineering practices of big programs like Atlas work for simpler systems?
- Is there a major difference between the engineering process of the “machine age” and the “systems age” even for the same basic function?

# History of Systems Engineering Summary

- Engineering has a long history
- Systems Engineering seems to be a more recent phenomenon
- Strongly related to management
- Post WWII government-funded projects played a major role in defining SE
  - NOTE:  Clausing, Axelband, Campbell article explores commercial SE and contrasts in with government SE

# Next Steps

- Do Assignment #1
- Do the reading assignments for session #2
  - INCOSE Systems Engineering Handbook ch 2.pdf
  - INCOSE Systems Engineering Handbook ch 4.pdf
  - Clausing_RCI Systems Engineering Process.ppt
  - Clausing_Commercial Product Development.pdf
- Come to session #2 at 8:30AM Thursday 10 June