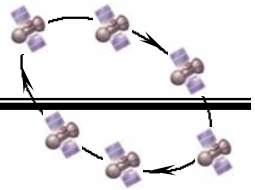
Virginia Tech

AOE



Systems Engineering

Chris Hall

AOE 4065

Fall 2005

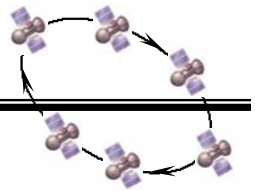
"Activity Matrix" Representing the Systems Engineering Process

	Logic → / Steps / Time Steps ↓	1 Problem Definition	2 Value System Design	3 System Synthesis	4 System Analysis	5 Optimi-zation	6 Decision Making	7 Planning for Action
1	Program Planning							
2	Project Planning							
3	System Development							
4	Production							
5	Distribution							
6	Operations							
7	Retirement							

Adapted from "Three-Dimensional Morphology of Systems Engineering," A. D. Hall, *IEEE Transactions on Systems Science and Cybernetics*, Vol. SSC-5, No. 2, April 1969, pp. 156–160

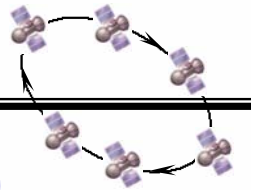
Seven Phases of Systems Engineering
(vertical axis of Activity Matrix)

- Program Planning – General programs and policies
  - HokieSpace, Inc. is dedicated to the training of new space systems engineers to meet future space exploration and commercialization needs
- Project Planning – Specific projects
  - Each year, HokieSpace takes on an entirely new slate of projects related to current space industry activities
- System Development – Design
  - AOE seniors carry out *preliminary* designs for these projects, applying the 7 steps of the horizontal axis to specific projects
- Production (or construction)
  - Occasionally these projects lead to flight hardware
- Distribution (and installation)
- Operation
- Retirement



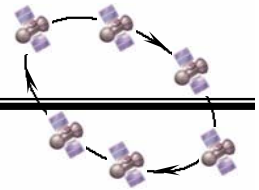
Seven Steps of Systems Engineering
(horizontal axis of Activity Matrix)

- **Problem Definition** – What is the problem, really?
- **Value System Design** – How will we know when we've found a good solution?
- **System Synthesis** – What are some alternatives which *could* satisfy objectives?
- **System Analysis** – How do each of these alternatives perform relative to objectives?
- **Optimization** – How good can we make each alternative perform?
- **Decision-Making** – Which alternatives are deserving of further study?
- **Planning for Action** – Plan for the next *phase*.



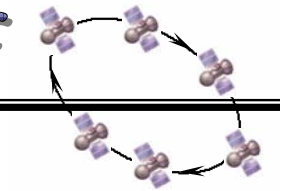
The 12 Products of Problem Definition

- A well-conceived **title** for the problem
- A **descriptive scenario**, explaining the nature of the problem and how it came to be a problem, and presenting as much history and data as can be prepared with available resources
- An understanding of what disciplines or professions are relevant to an attack on the problem
- An assessment of the scope of the problem
- A determination of the societal sectors involved
- An identification of the actors to be involved in the problem-solving situation
- An identification of **needs**
- An identification of **alterables**
- An identification of major **constraints**
- Some partitioning of the problem into relevant elements
- Some isolation of the subjective elements of the problem
- A description of **interactions** among relevant elements of the problem



Needs, Alterables & Constraints

- Needs
  - A condition requiring (a) *supply*; or (b) *relief*
  - A lack of something (a) *required*; (b) *desired*; or (c) *useful*
  - Example: Decrease likelihood of loss of space-based assets
- **Alterables:** things pertaining to the needs that can change
  - controllable to help achieve needs and objectives
    - Examples: orbit selection; attitude stabilization approach; battery technology
  - uncontrollable but subject to change
    - Examples: national policy; available funding; international environment
- **Constraints:** limiting boundaries of the system
  - Examples: existing debris, existing satellites, international law



An Example "NAC" Table

Category	Element
Needs:	Launch payload spacecraft from Earth to Mars orbit
Alterables:	Tether/payload spacecraft rendezvous method and interface
	Launch vehicle
	Orbit design
	Propulsion method throughout mission
	All subsystem level design
	Material selection
Constraints:	Under 3-g accelerations imposed on payload spacecraft
	Rendezvous with payload spacecraft in LEO
	Must accommodate payload spacecraft shape and size
	Must not violate international law
	Launch six 200 kg payload spacecraft every Earth-Mars alignment
	Lifetime of 30 years
	Launch TLS by 2012
	Use momentum exchange transfer method

Systems Engineering Process

	Logic → / Steps / Time Steps ↓	1	2	3	4	5	6	7
		Problem Definition	Value System Design	System Synthesis	System Analysis	Optimi-zation	Decision Making	Planning for Action
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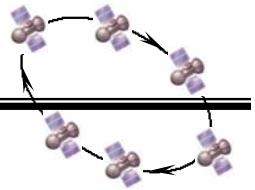
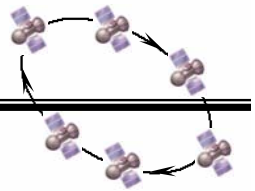


Value System Design

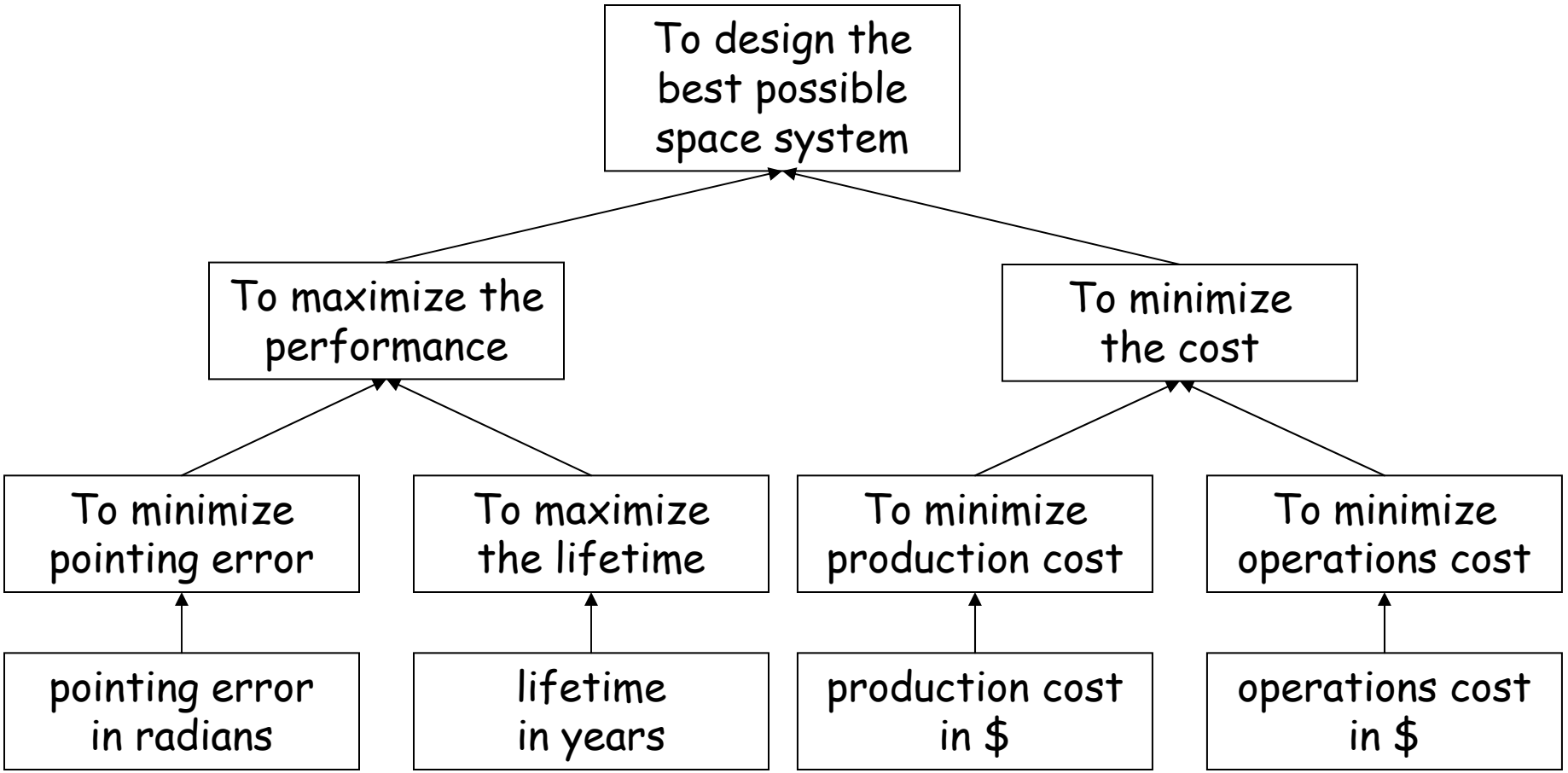
- Values can be
  - instrumental, or extrinsic: associated with means to attain ends; *e.g.*, monetary value, value diminished by consumption
  - intrinsic: associated with the ends themselves; *e.g.*, goodness, truth, happiness, ethics-based values
- To determine objectives:
  - ask "Chief Decision Maker" (explicit, but not usually feasible)
  - determine valued aspects or problems of current system (implied objectives)
  - make some up and show them to the CDM for feedback
  - look at some similar systems
- Three outputs of VSD:
  - definitions of objectives
  - relation between objectives and needs/constraints
  - definition of how to measure attainment of objective



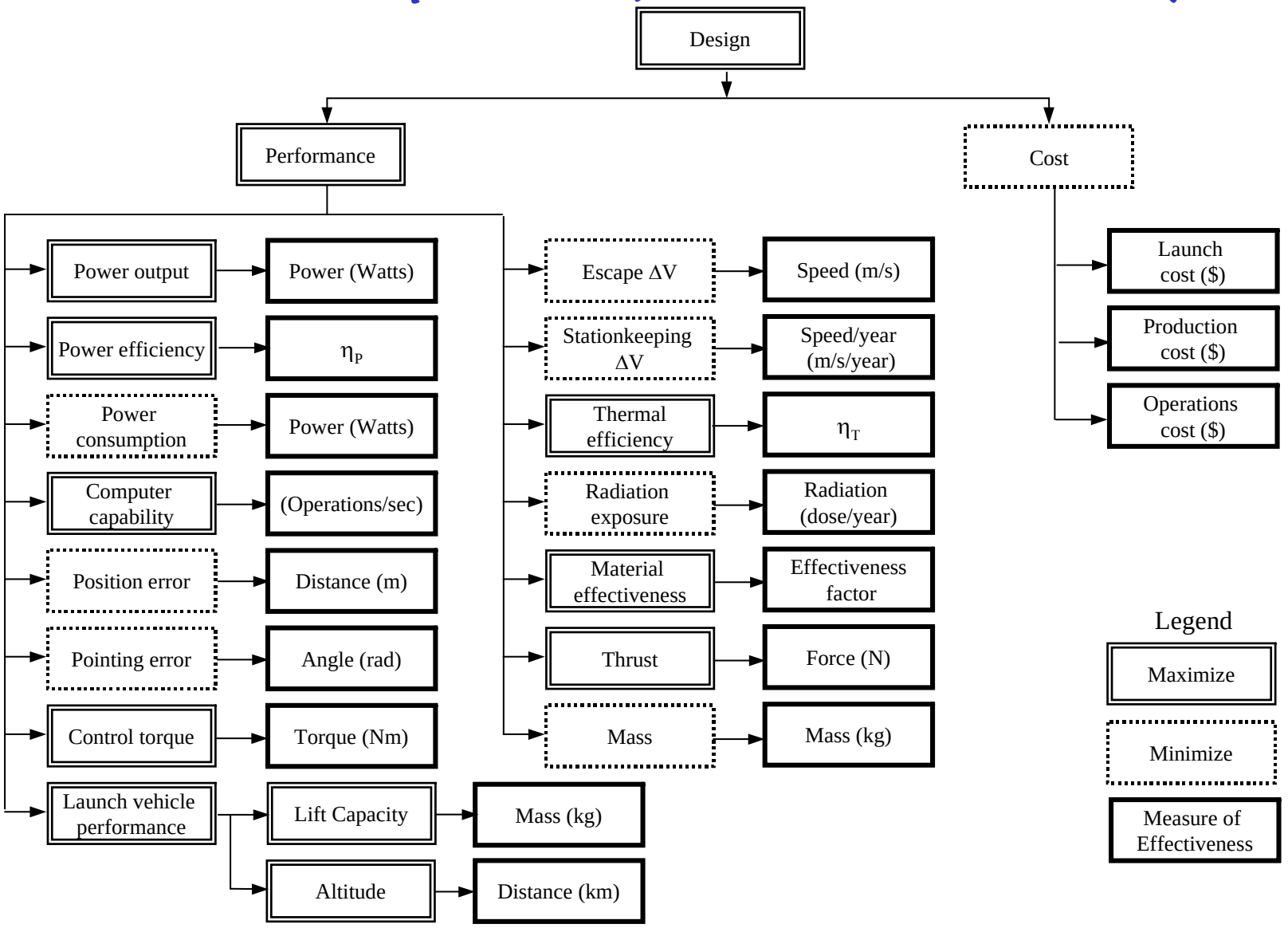
Value System Design

- Given a set of alternatives, what attributes of solving the problem will allow us to select the "best" solution?
- Develop objectives of the form: TO (VERB) (OBJECT)
- Two broad categories:
  - efficiency: how well does it do what it does?
  - effectiveness: how well does what it does match requirements?
- Others:
  - technical: traditional, quantitative, operational, measurable
  - economic: cost, profit
  - psychological: aesthetics, comfort, style - qualitative & subjective
  - political: acceptability to the powers that be

Value System Design



An Example Objective Hierarchy



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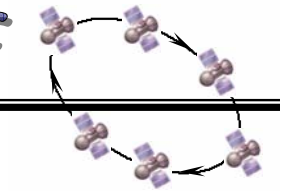

System Synthesis

- Generate a whole bunch of feasible solutions
- Feasibility issues:
  - technological: can it be done in timeframe?
  - constraints: does it violate any?
  - are subsystems compatible?
  - does it address at least some of the needs?
- Other than feasibility, withhold judgment here.
- Examine the ideal solution. What would have to change to make it feasible?
- Look for analogues
- Chinese menu approach: Disassemble problem, solve subproblems, put solutions together

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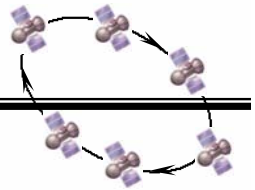

System Analysis (Modeling)

- A model only needs to focus on the aspects that are relevant to the problem
  - determine those elements of problem definition, value system, and synthesis that are relevant
  - determine the relationships between these elements
- Should be
  - valid
  - manageable
  - able to differentiate alternatives
  - complete with respect to the value system design
- Resolution
  - binary: yes/no; on/off; to be or not to be
  - finite number of classes: color; type; model #
  - real numbers: thrust; mass; height; price

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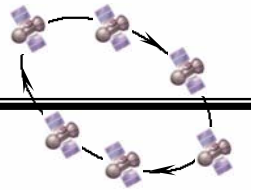

Remaining Steps

- Optimization
  - Make each alternative "as good as possible"
- Decision-making
  - Rank the alternatives and decide which deserve further study
- Planning for action
  - Plot a course of action for the next iteration through the 7-step process