Recinto Universitario de Mayagüez
universidad de puerto rico

Systems Engineering Overview

Axel Claudio
Alex Gonzalez

Objectives

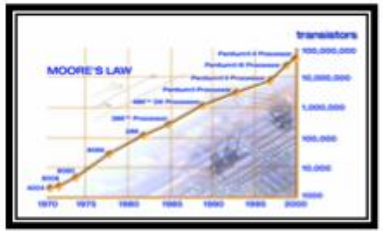
- Provide additional insights into Systems and into Systems Engineering
- Walkthrough the different phases of the product lifecycle
- Discuss why it is important to have good requirements, interfaces, designs and that they are well defined
- Provide a brief overview of how every engineering role is accountable and important within the System

Why this is important?

- Modern societal and economic advancement depends on successfully designing, building, and operating efficient large scale systems
- Despite rigorous processes, some systems still fail
  - Space shuttle accidents, NE US power grid blackouts, Gulf oil spill
- Failures often traced to uncontrolled, unanticipated, and unwanted interactions between elements
- More, and more detailed, processes not the answer (process still imp.)
- Its about achievement of “an elegant design”; one that:
  - Works as intended – produces intended result
  - Is robust (e.g., graceful degradation to failures, changes in environments, etc.)
  - Is efficient, producing the desired result with lower/fewer resources than alternatives
  - Minimizes unintended actions, side effects, and consequences
- Core concern of engineers should be ensuring these qualities

Driving Factors to Modern System Design

- Advanced Technology and Risks
- Increased Competition
- Increased Specialization
- Increased requirements/capability
- Rapid changes in technology
- Fast time-to-market most critical
- Increasing pressure to lower costs
- Increased presence of embedded information and automation systems that must work correctly



Why do we update systems? One of the principles of humanity is constant evolution…

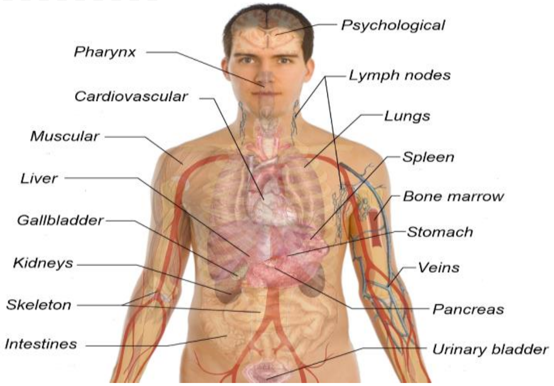
What is a System?

- NASA: a construct or collection of different elements that together produce results not obtainable by the elements alone
- ISO/IEC: a combination of interacting elements organized to achieve one or more stakeholder's purposes
- INCOSE: An integrated set of elements, subsystems, or assemblies that accomplish a defined objective
- In all definitions, "elements" include people, processes, facilities, etc., as well as typical HW and SW
- In all cases, the system context is a function of the task at hand, and of the stakeholder's interests and/or responsibilities

Examples of Systems

- Engineered Systems
  - Mechanical Pencil
  - An automobile
  - A subway system
  - Space Science Mission

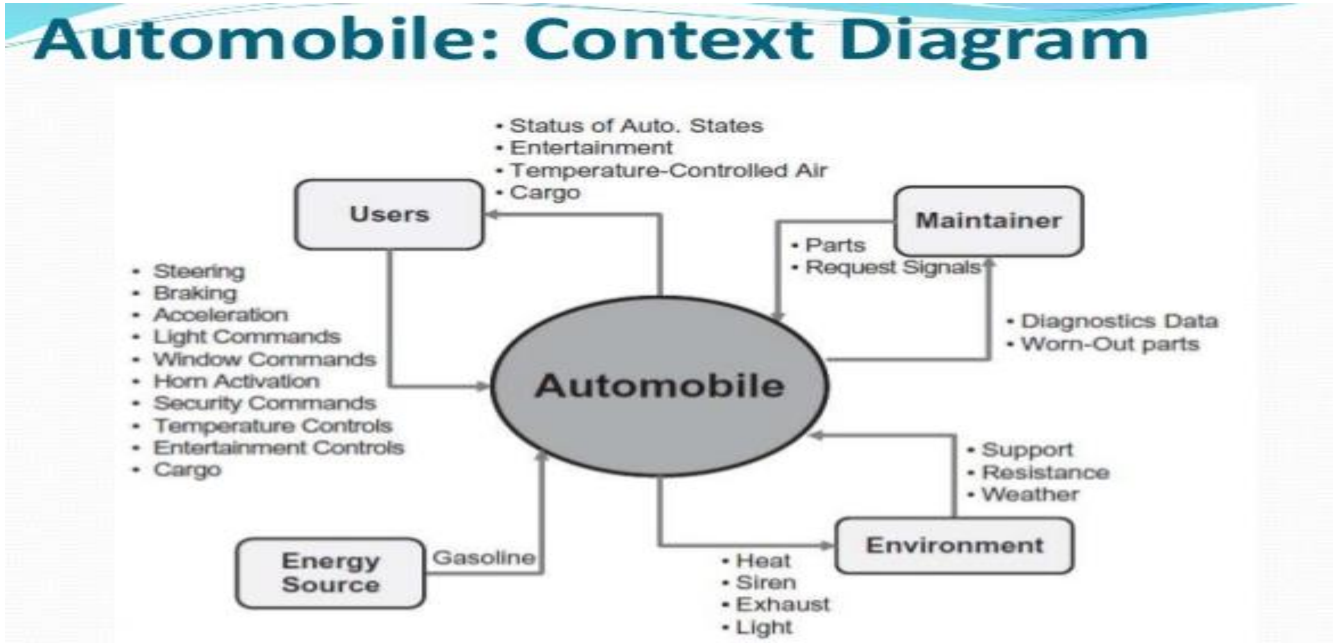
- Naturally occurring systems
  - A rainforest
  - The oceans
  - Human body



- Non-engineered human systems
  - Legal system
  - Monetary system

System Context Diagram

- System Context Diagrams represent all external entities that interact with a system. This diagram depicts the system at the center, as a black box (with no details of its interior structure), surrounded by all its interacting systems, environments and activities.
- The objective of the system context diagram is to emphasize attention on external factors, stakeholders and events that should be considered in developing a system such that a complete set of systems requirements and constraints can be developed.



Let's give context to another System…

What is System Engineering?

- **An approach and means to enable the realization of successful complex systems**
  - Focus is on customer/stakeholder's needs and required functionality
  - Follows end-to-end process, including documenting requirements, design development and realization, and system validation
  - Considers the complete problem, including:
    - Operations
    - Cost and schedule
    - Performance
    - Training and support
    - Test, manufacturing
    - Disposal

Adopted from INCOSE TP=2003-002-03.2, Jan, 2010

What is the difference between Systems Engineers and other engineers?

- **Systems Engineers focus on the system as whole**
  - Focus is on the relationship between components (and by extension interfaces) rather than on the components.
- **Systems Engineers' primary responsibility is to guide the product thru the lifecycle process**
  - Although systems engineers do considerable engineering themselves (especially on interfaces), their primary concern is overseeing the engineering efforts of those working on individual components to ensure that their work remains consistent with that of other component engineers.
  - System engineers ensure system "balance" – especially maintaining a balance in the requirements, design & development of the different interfaces among the various system components within.
- **System Engineers attempt to "bridge" the work of others**
  - Systems engineers "pull-together" the expertise of domain experts in multiple disciplines
  - Systems Engineers rely on having more 'breadth' but less 'depth' than other engineers within system. (Top level vs Bottoms up)

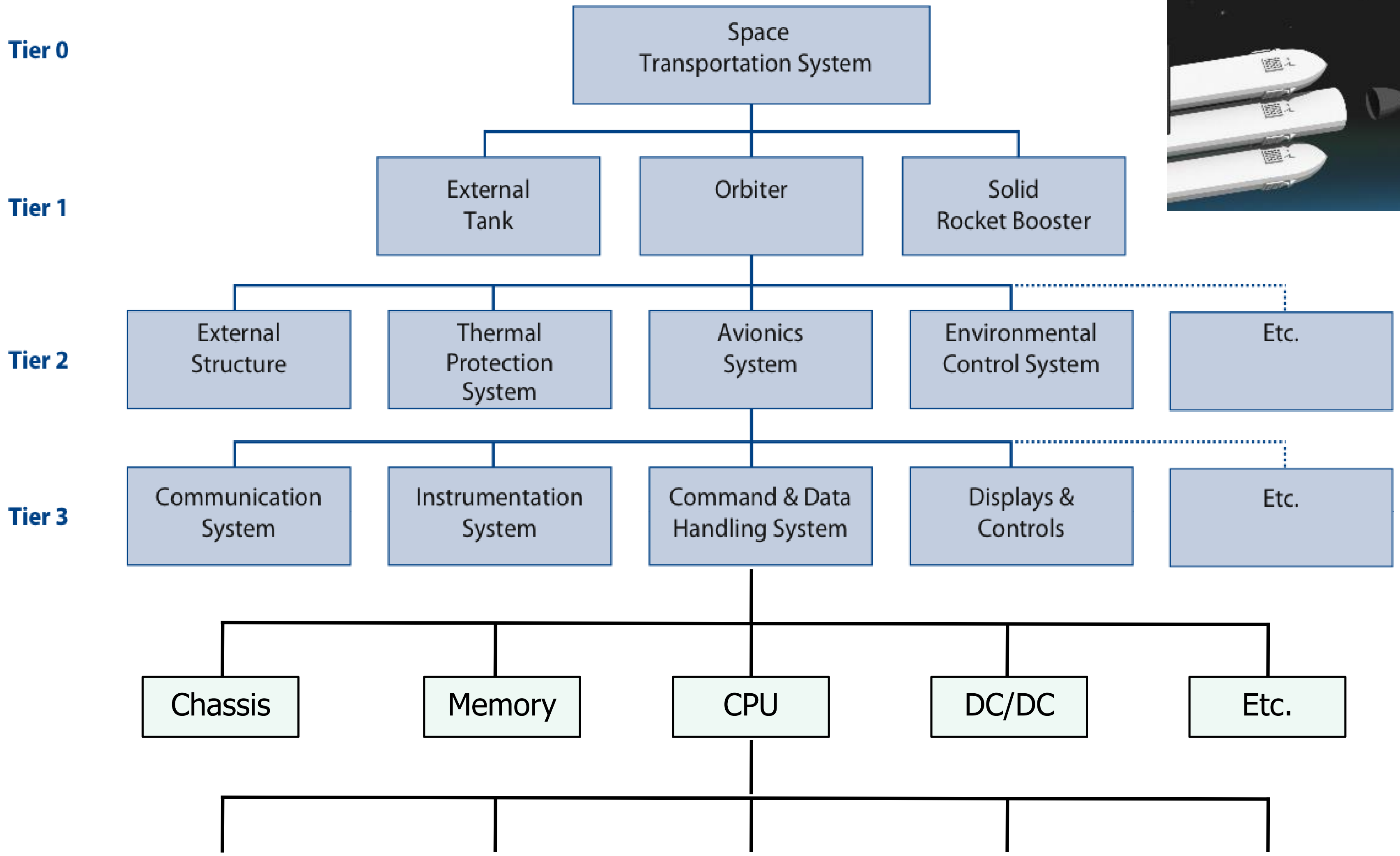
Roles of a Systems Engineer (1 of 2)

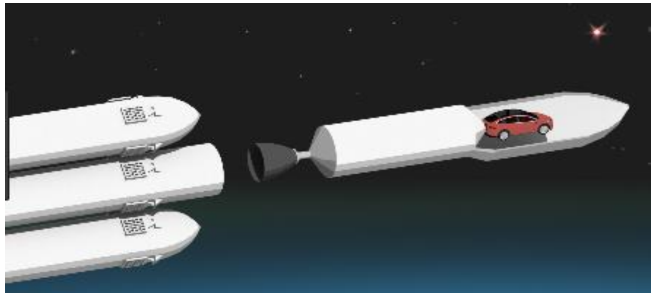
- Technical leader of the associated element
  - System-of-systems, system, subsystem, …
  - Staff or support roles also filled by systems engineers
- Ensures the team is:
  - “Doing things right” and…
  - “Doing the right things”
- Shares some roles of project control with the PM
  - Ensures programmatic requirements that are met
- Builds & maintains team unity, camaraderie, common purpose
  - There is no “I” in “Team”

Roles of a Systems Engineer (2 of 2)

- Focuses on the system as a whole
  - Defines the task(s) and the requirements - in many contexts
  - Keeps "total life cycle" perspective
  - Identifies the separable elements or blocks
  - Characterizes the intended relationships and interfaces
    - Including the dynamic and/or non-linear behavior
  - Verifies that the products operate as intended for the user
- Applies multidisciplinary and interdisciplinary skills
  - Technical breadth
  - Engineering judgment

System Organizations or Hierarchies

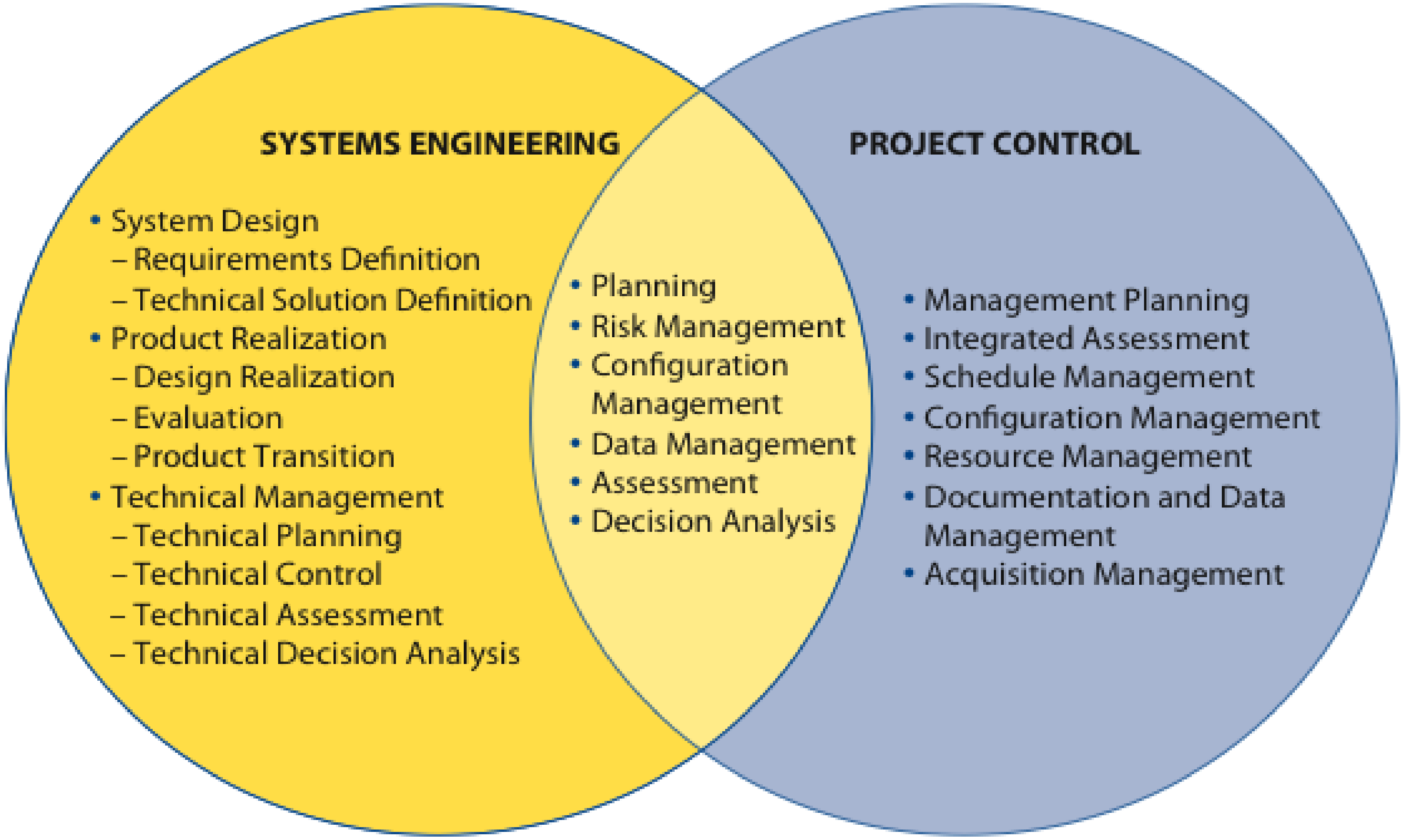




How did Elon Musk, Tesla and Space X have a successful Falcon Heavy Rocket Flight?

Adapted from NASA System Engineering Handbook

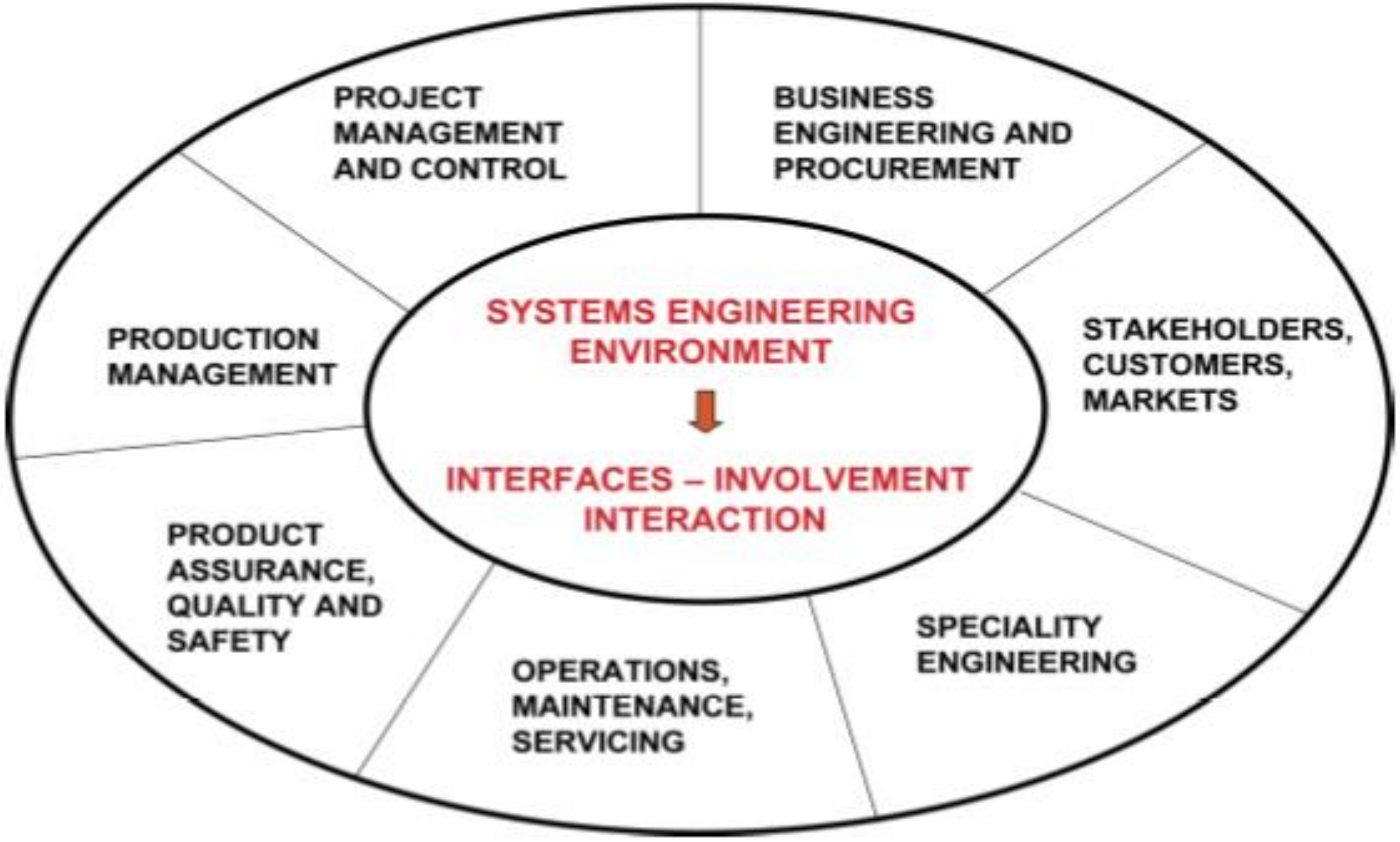
Systems Engineering Environments



Systems Engineering in the context of project management

From NASA System Engineering Handbook

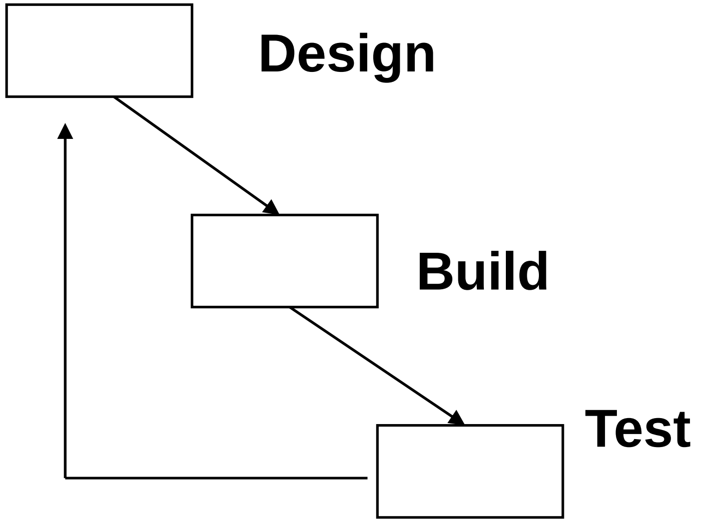
Systems Engineering’s Critical Interactions

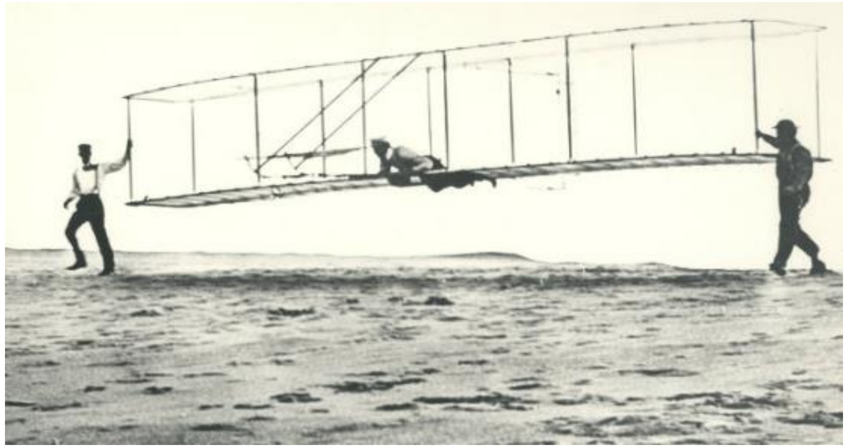


From INCOSE TP=2003-002-03.2, Jan, 2010

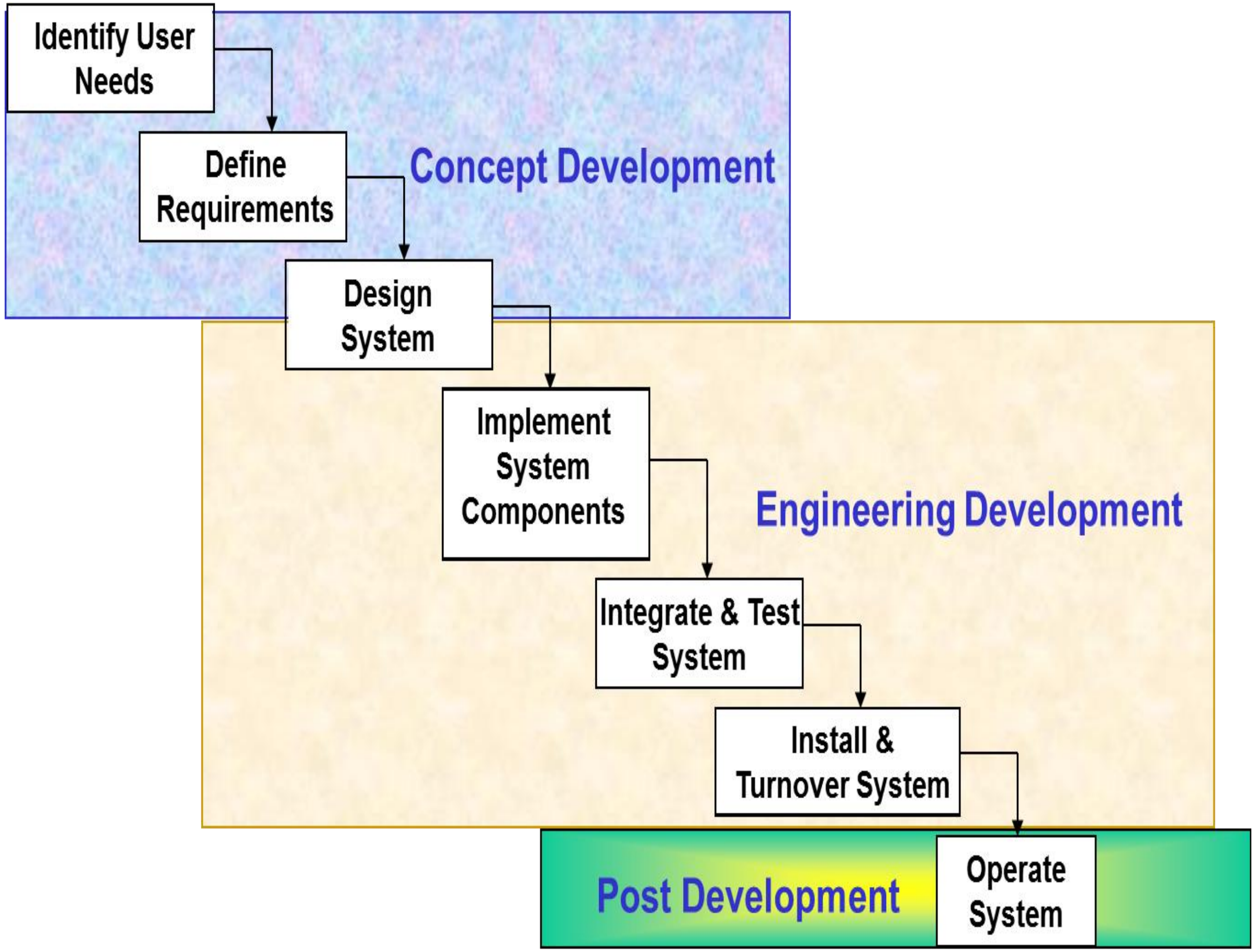
Comparison of Approaches

Historical Model – Trial & Error



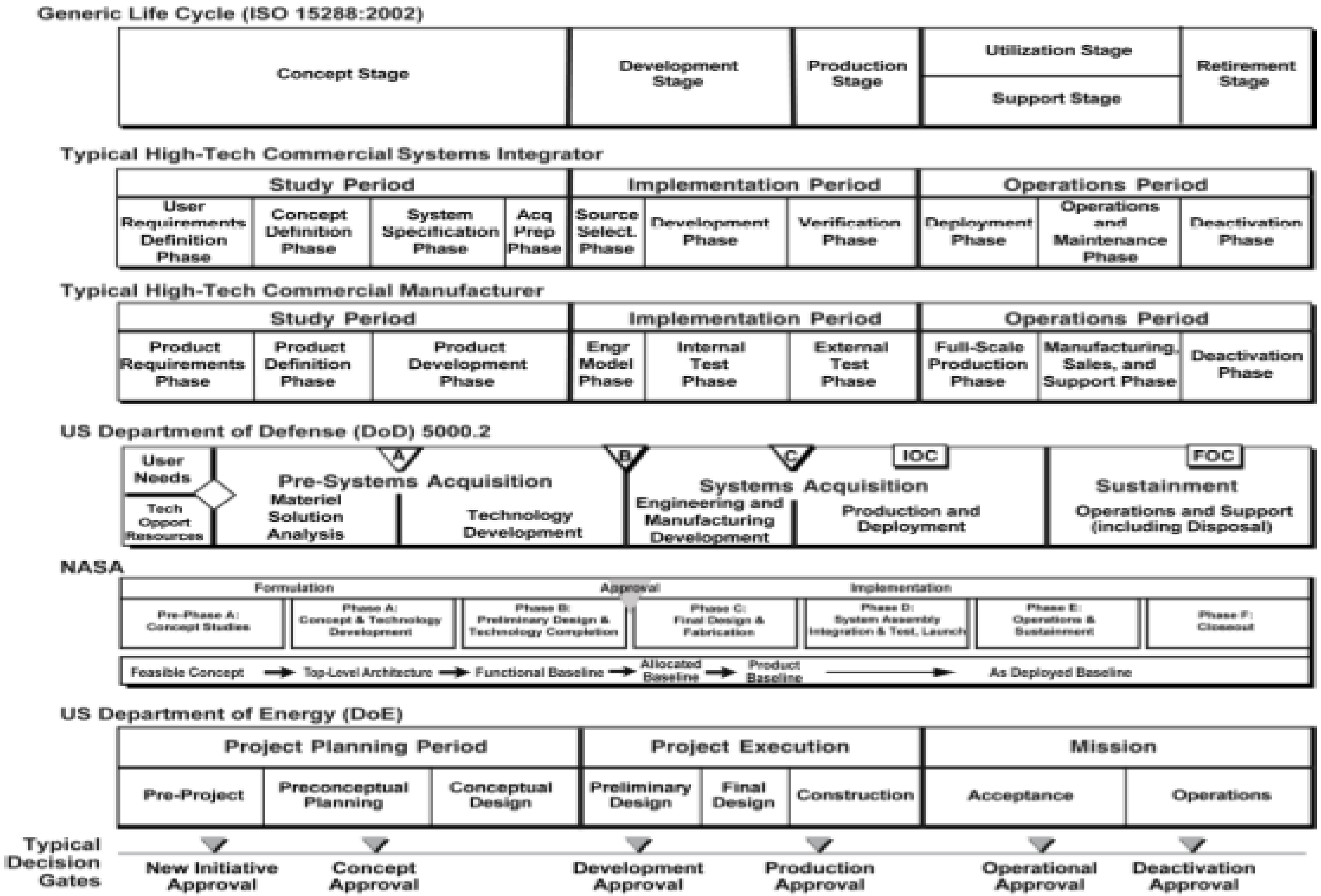


System Life Cycle - Generic



Which approach would Amazon, Google, Boeing or Raytheon take?

Sample of Project Life Cycles

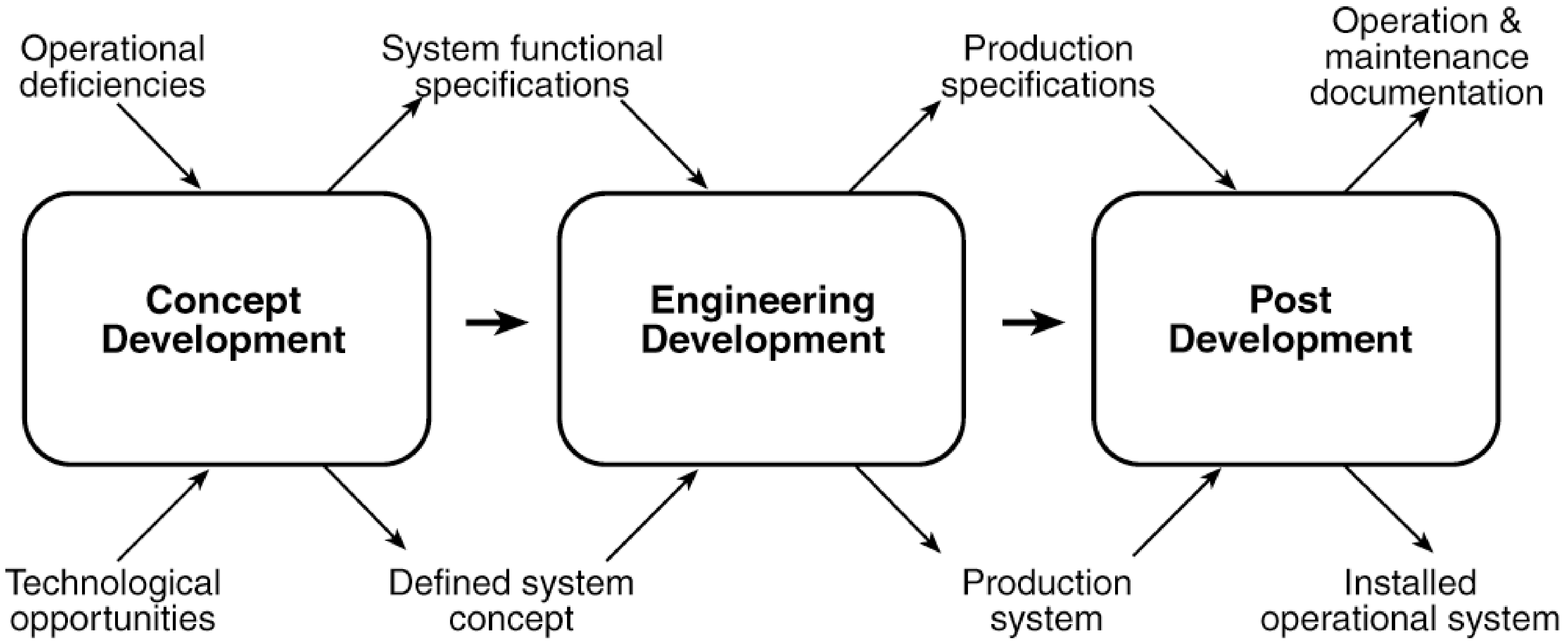


Products are gradually developed and matured →

From INCOSE TP=2003-002-03.2, Jan, 2010

Principal Stages in a System Life Cycle

System Models (Baselines)



From Kossiakoff and Sweet

Products

System Life Cycle Stages

- Concept Development Stage
  - Formulation and definition of a system concept perceived to best satisfy a valued need
- Engineering Development Stage
  - Translation of the system concept into a validated physical system to meet the stated requirements
- Post-Development Stage
  - Execution of production, deployment, operation, and support
- Disposal
  - System retirement
  - Safe disposal of environmentally sensitive materials

Concept Development Stage

- Needs Analysis
  - Is there a valid need for the new system?
  - Is there a feasible approach to satisfying the need?
  - Is available technology likely to be adequate, or close or not?
- Concept Exploration
  - What performance is required to meet the perceived need?
  - Is there even one feasible approach that is affordable?
- Concept Definition
  - What are the key characteristics?
  - What is the desired balance of operational capability and cost?
  - Which concept seems “best”?

Engineering Development Stage

- Technology Validation
  - Identification and reduction of risk
  - Known unknowns and unknown unknowns
  - Basis for converting functional requirements into system specs
- Engineering Design
  - Detailed engineering design using formal and detailed processes
  - "ilities" of paramount important (reliability, maintainability, producibility, …
  - Systems engineer must keep his eye on the complete system & interfaces
- Integration and Evaluation
  - Flows from the engineering design
  - Concern is on total system performance and capabilities (& shortcomings)
  - Informal and formal testing in realistic environments

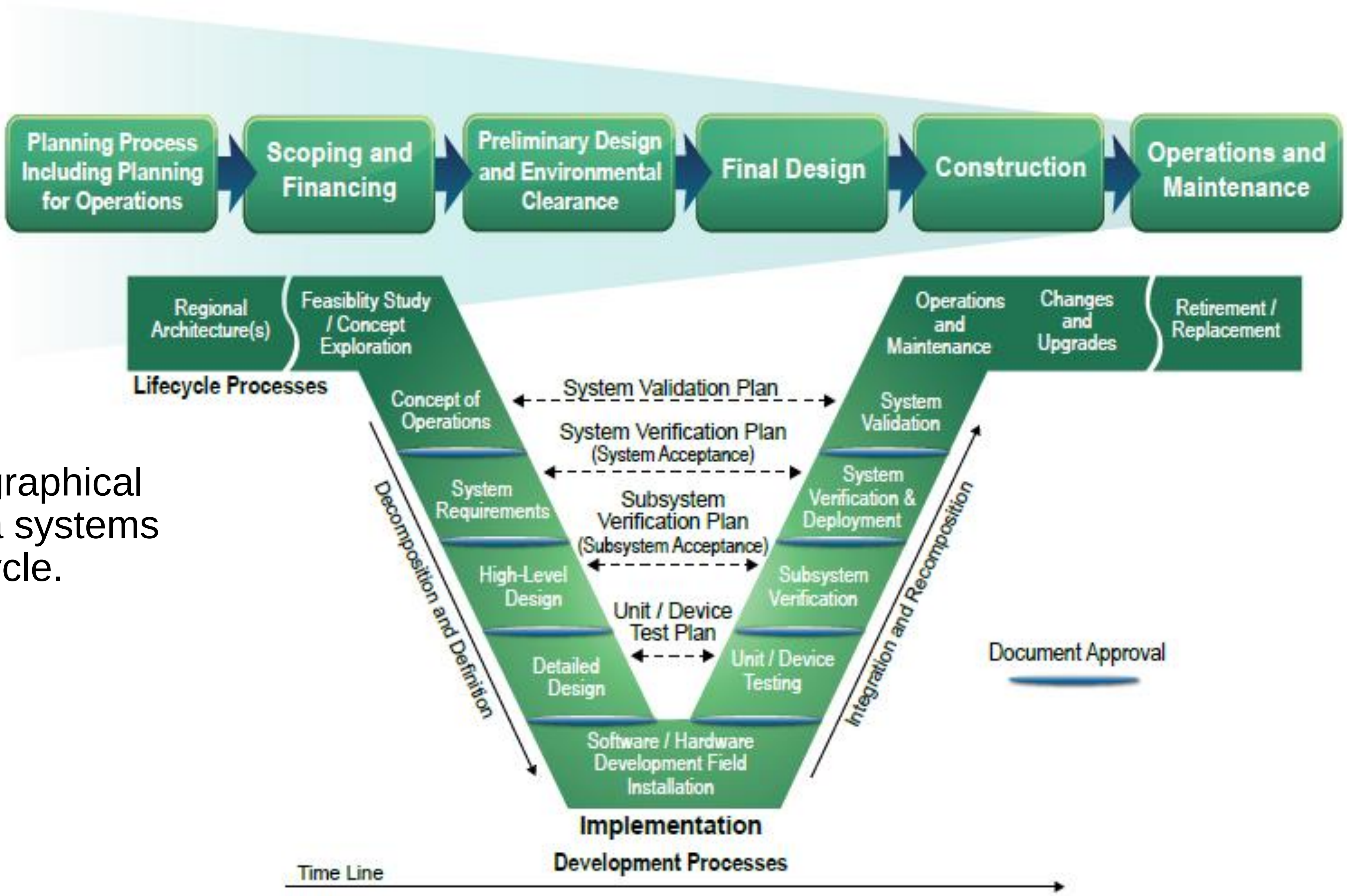
Post-Development Stage

- Production
  - System engineers are critical bridge from development to production
  - Production considerations early in life cycle are critical
  - Production cost containment can be problematic
    - Configuration management
    - Supply chain management (quality, consistency, schedule)
    - Process repeatability, material variations, “innocent” process changes
  - Low Rate Initial Production (LRIP) utilized to work out materials and process problems; requirements verification
- Operation
  - Training programs
  - Maintenance
  - Logistics
  - Upgrades

Disposal

- Recognized at project initiation
  - Determine sensitive materials
  - Where will they be stored?
  - Can the entire system be "mothballed"?
- Environmental impact
  - Heavy metals
  - Nuclear materials

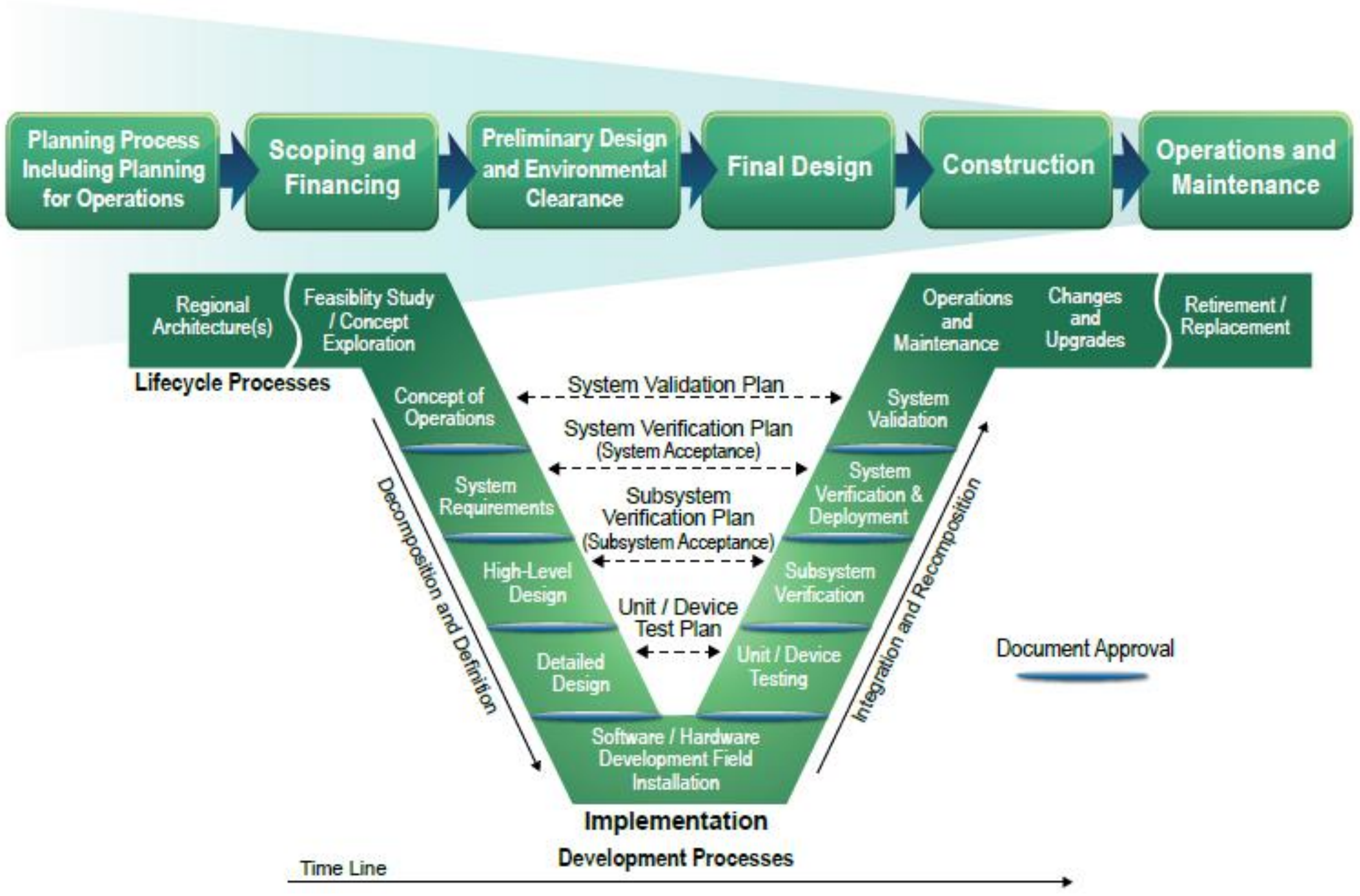
"Systems Engineering V"



The V-model is a graphical representation of a systems development lifecycle.

Walkthrough Example

From the example used to create the Context Diagram let's walk through the "Systems Engineering Vee" and take it through and come up with ideas.



Summary

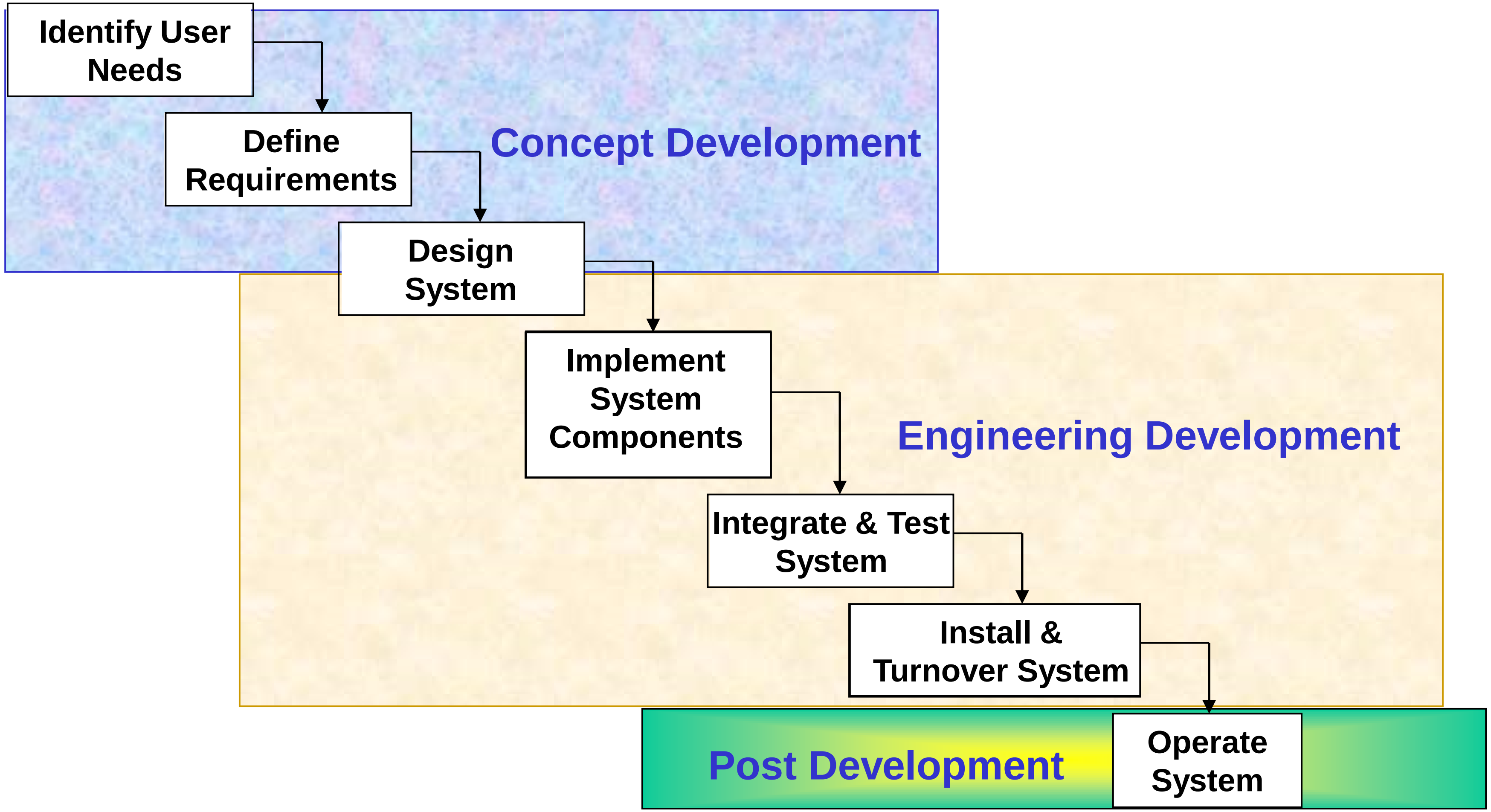
- Systems Engineering Practices have evolved in response to the advent of more complex systems and a more complex business environment

- Those practices are designed to enable the development of more complex systems more efficiently and with greater transparency

- A system engineering method, modeled after the basic scientific method, can be applied to systems engineering problems

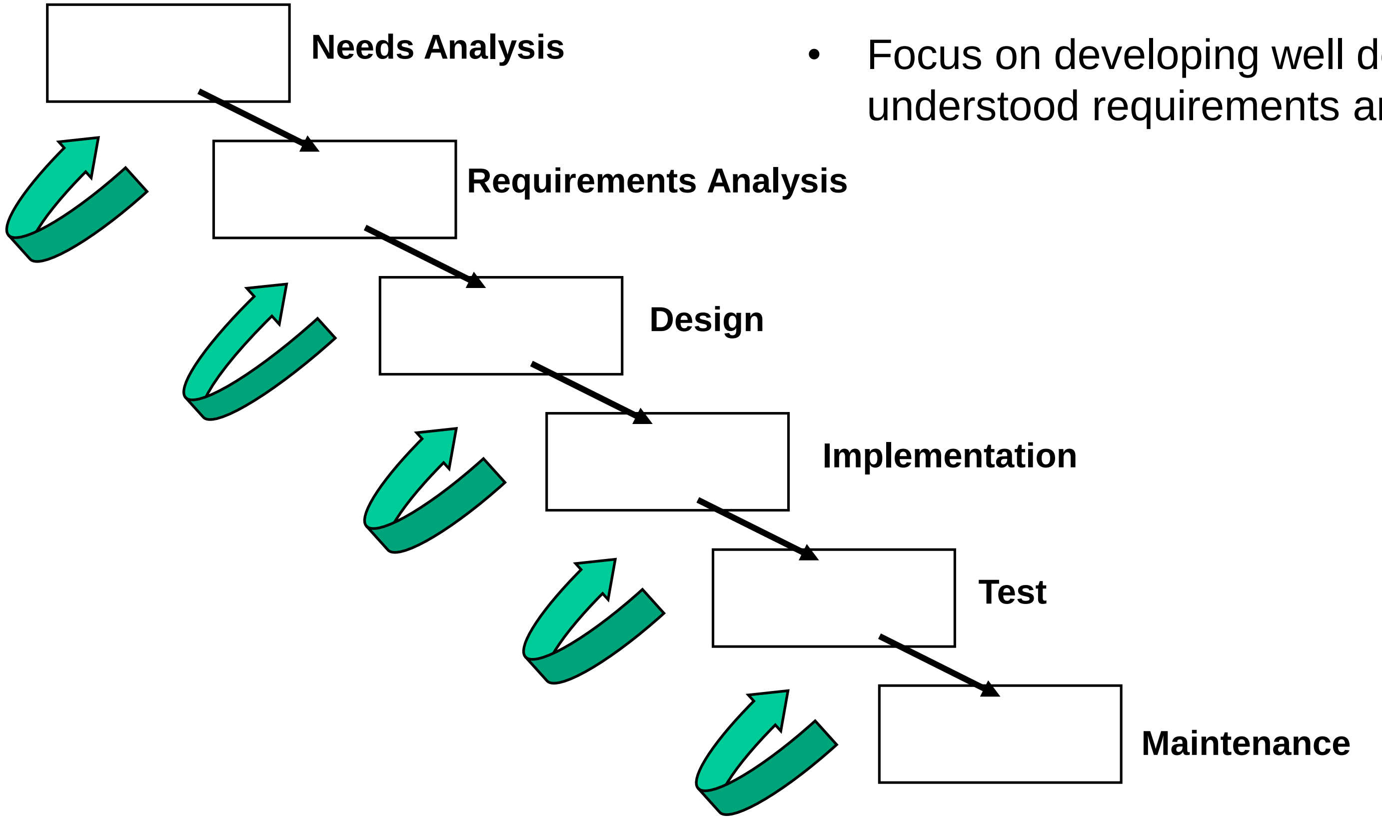
Back up

System Life Cycle—Generic (Computer Science Corporation)



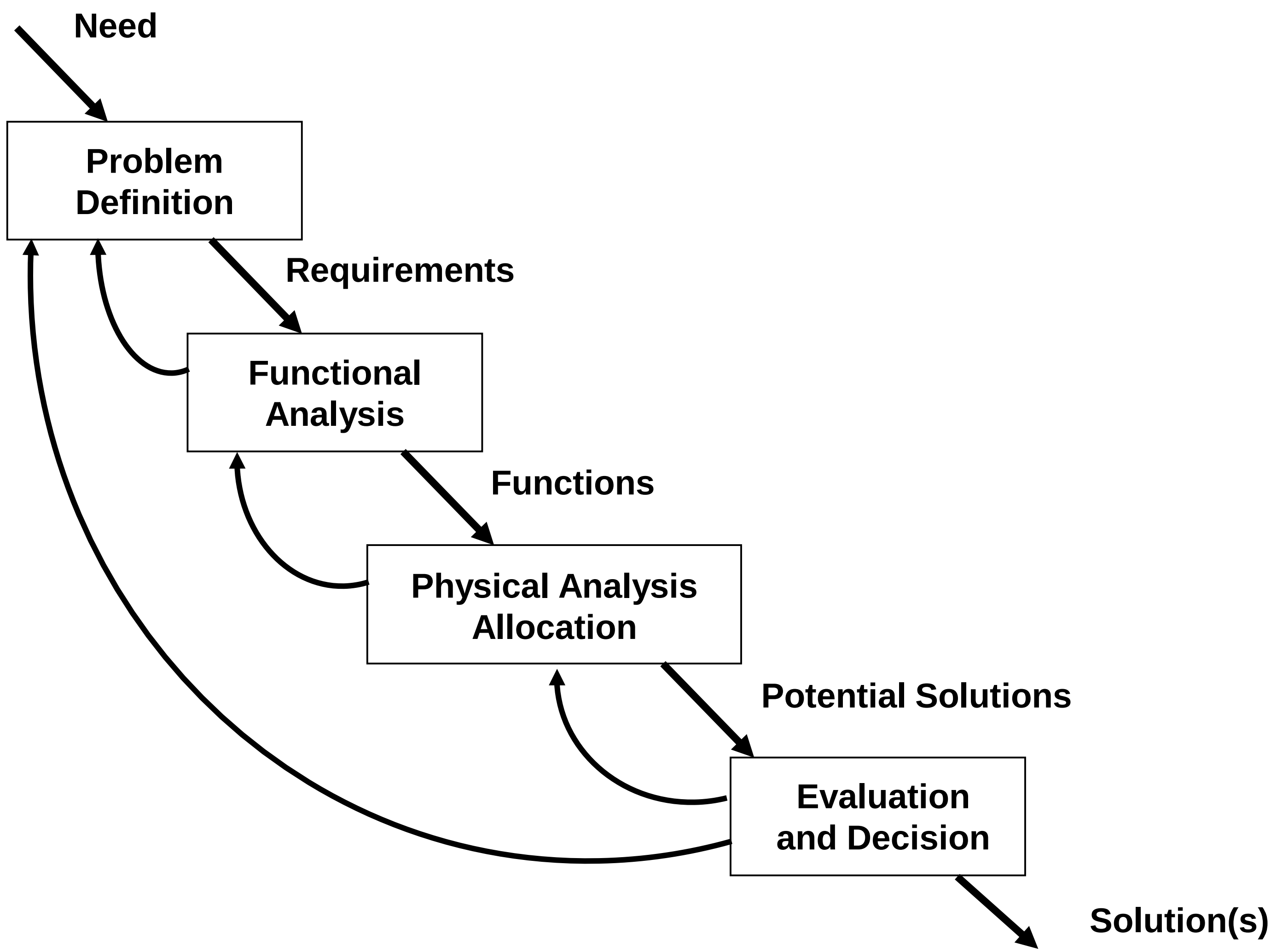
Product Lifecycle

- Iterative and Agile way of operating through the different phases
- Feedback from one stage to the other
- Focus on developing well defined and understood requirements and design



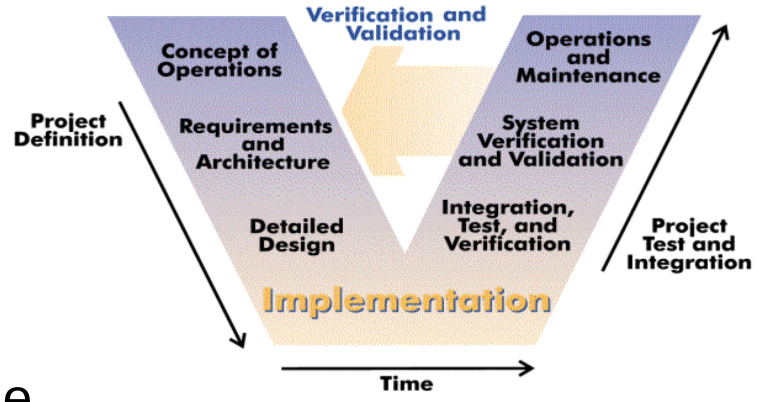
Boehm, B. W., A Spiral Model of Software Development and Enhancement, TRW Defense Systems Group, 1987

Systems Engineering Method



As defined by Kossiakoff and Sweet

Systems Engineering Lifecycle by stage



- Definition: Define what will be done
- Design: Determine how it will be done
- Development: Build the system
- Disclosure: Communicate with the customer and other stakeholders what is being done
- Demonstration: Demonstrate that what is being done will work

Systems Engineering View Attributes (1/2)

- System Engineering must take a Top Down view
  - Must be able to view the system as a whole (as a black box with no internals) to see its place in the environment
  - Focuses on decomposition methods to partition and aggregate the problems into solvable units with defined interfaces
- System Engineering must take a Life Cycle view
  - Development, production, distribution, operation, maintenance, and even retirement and disposal must be considered throughout conceptual and system design

Systems Engineering View Attributes (2/2)

- Systems Engineering must have a user requirements focus
  - The user is the ultimate judge of success
  - Therefore, the user requirements should drive the design process from the beginning
- Systems Engineering must hold interdisciplinary expertise
  - Balance between technical disciplines
  - Balance between designers, users, program management, maintainers, etc.
  - SE discipline must be team oriented and broad in technical expertise