IP504914 System engineering
Best Practice Module

Week 37 – Classes Plan

Henrique Gaspar - Fall 2014
hega@hials.no - B410 (AMO)

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Fundamentals - Monday, Sept 8th

- **Morning:**
  - Introduction & Course Program
  - What is a System?
  - Systems Hierarchy
  - Systems Complexity
  - Decomposition and Encapsulation
  - Practical Example – Physical Systems
  - Class, instances, objects
- **Exercise:**
  - Complexes systems around us
  - Boundary of a system
  - Hierarchies
  - Structural Aspects
  - Functionalities
  - Attributes

Literature:

1. Meadows, D. "Systems Thinking", 2014
2. Simon, H. "Architecture of Complexity", 1962
3. INCOSE, "Systems Engineering Handbook", 2010
4. Dahl, J. "Systems Engineering Course at NTNU", 2009
5. Oliver, D. et al. Engineering Complex Systems with Models and Objects", 1996
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7. Gaspar, H.M. "Handling aspects of complexity in Conceptual Ship Design", 2012
8. NASA "Systems Engineering Handbook", 2007.

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Design - Monday, Sept 8^{th}

- **Afternoon:**
  - Artificial x Natural System
  - Design Principles
  - Design Methods
  - Design of Systems, Subsystems and System of Systems
  - Examples
- **Exercise:**
  - Designing Engineered Systems
  - Describe Form-Function Concept
  - Present "Design Mapping" process
  - Decompose goals and how to reach these goals
  - Applying basic design models

Literature:

1. Coyne, R. et al, "Knowledge-Based Design Systems", 1990
2. Erikstad, S. O. "Design Methods – NTNU Course", 2009
3. Suh, N. "Principles of Design", 1990
4. Simon, H. "Sciences of Artificial", 1996

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Lifecycle - Tuesday, Sept 9^{th}

- **Morning:**
  - Lifecycle Characteristics
  - Decision Gates
  - Lifecycle stages
    - Pre-concept
    - Concept
    - Development
    - Production
    - Operation
    - Support
    - Retirement
  - Value Chain Overview
  - Examples
- **Exercise:**
  - Propose a lifecycle for your system
  - Apply basic lifecycle method
  - Brief discussion on layers and boundaries

Literature:

1. INCOSE, "Systems Engineering Handbook", 2010
2. Haskins, C., "Systems Engineering Handbook – A guide for Lifecycle Processes and Activities", 2006
3. Ulstein, T., and Brett, P. O. "Critical systems thinking in ship design approaches." International Maritime Design Conference - Glasgow (2012).
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Product and Process Tuesday, Sept 9th

- **Afternoon:**
  - Product and Process
  - Flowing through the system
  - System Architecture Process
  - Product Creation Process
  - Basic sources for process managements
  - Examples
- **Exercise:**
  - Product / Process distinction
  - Decomposing your process
  - Product flow through process
  - Establish form/function criteria

Literature:

1. Meadows, D. "Systems Thinking", 2014
2. INCOSE, "Systems Engineering Handbook", 2010
3. Muller, G. "System Architecting", 2010
4. PMBOOK, "Project Management Body of Knowledge"
5. Michael, J. "Systems Approaches to Management", 2000

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5 Aspects - Wednesday, Sept 10th

- **Morning:**
  - Five Aspects of Complex Systems
    - Structural
    - Behavioral
    - Contextual
    - Temporal
    - Perceptual
  - Connect to Product and Process
  - Examples
- **Exercise:**
  - Apply five aspect taxonomy to the case
  - Discuss system characteristics for each of the aspects
  - Combine methodologies

Literature:

1. Rhodes and Ross, "Shaping in Socio-Technical System Innovation Strategies using a Five Aspects Taxonomy", 2010
2. Rhodes and Ross, "Five Aspects of Engineering Complex Systems - Emerging Constructs and Methods", 2010
3. Gaspar, H.M. "Handling aspects of complexity in Conceptual Ship Design", 2012

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Decision Making
Wednesday, Sept 10th

- **Afternoon:**
  - Perceptual Aspect
  - How "good" is perceived?
  - Decision Making
  - Measures of Merit
  - Decision Matrix
  - AHP
  - Decision Tree – what is the "value" of a decision?
  - Examples
- **Exercise:**
  - Develop a simple decision making tool for your case
  - Basic AHP
  - Decision Tree for Key choices

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1. Rhodes and Ross, "Five Aspects of Engineering Complex Systems - Emerging Constructs and Methods", 2010
2. Haskins, C., "Systems Engineering Handbook – A guide for Lifecycle Processes and Activities", 2006
3. March, J. "A Primer on Decision Making: How Decisions Happen", 1994
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Combining Methods
Thursday, Sept 11th

- **Morning:**
  - Near-decomposable systems
  - Combining Methods
  - SE techniques x non-SE Techniques
  - RSC and Epoch-Era Analysis
  - Case Studies
- **10-16 – Project Proposal:**
  - Sketch a proposal
  - Elevator pitch
  - 2 slide presentation:
    - Introduction
    - Scope
    - Objective
    - Milestones
    - Deliveries
  - What is your focus (es)?

Literature:

1. Simon, H. "Sciences of Artificial", 1996
2. Gaspar, H.M. "Handling aspects of complexity in Conceptual Ship Design", 2012
3. Gaspar, H. et al., "Handling temporal complexity in the design of non-transport ships using epoch-era analysis", 2011
4. Ross, A.M.,et al. "Responsive Systems Comparison Method: Dynamic Insights into Designing a Satellite Radar System,", 2009
5. Muller, G. "System Architecting", 2010

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Best Practice – Ulstein Group Friday, Sept 12th

ULSTEIN

- **Agenda:**
  - 9:45 – Arrival and introduction (HG)
  - 10 - 11:00 Spirit of Innovation (ØK)
  - 11:00 – 11:45 Lunch
  - 12:00 – 13:30 Visit Ship Yard (HG)
  - 13:45 – 15:45 Ulstein Best Practices (POB)
  - 15:45 Closing Remarks

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Purpose of the Course

- Introduce Systems Engineering (SE) basic principles, methods and thinking to master students at HIALS
- Provide references that can be used as starting point to apply SE in future cases
- Provide examples of SE applications in complex artificial systems
- Make the students practice the SE principles with regular tasks, to be performed during the course, plus a final project
- Students can apply later these principles/techniques/ thinking in their Maser Thesis

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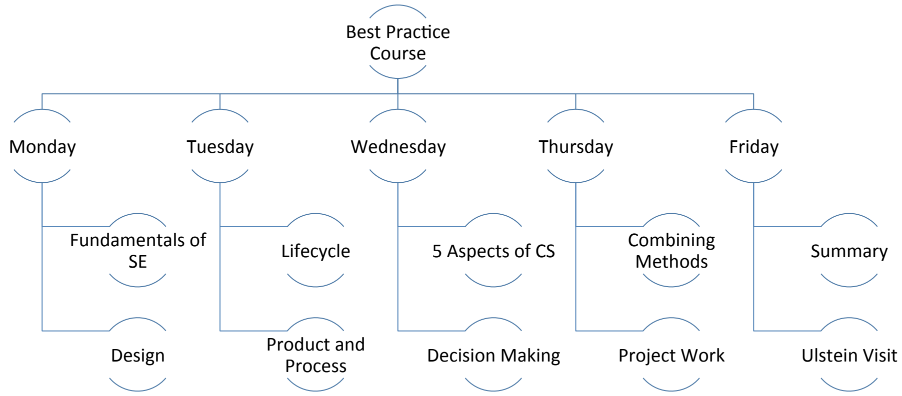
Offer & Expectation

- **Offer:**



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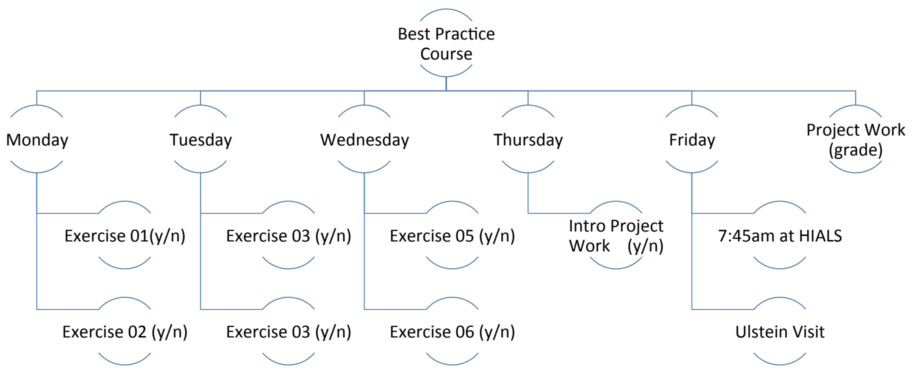
Offer & Expectation

- **Expectations:**



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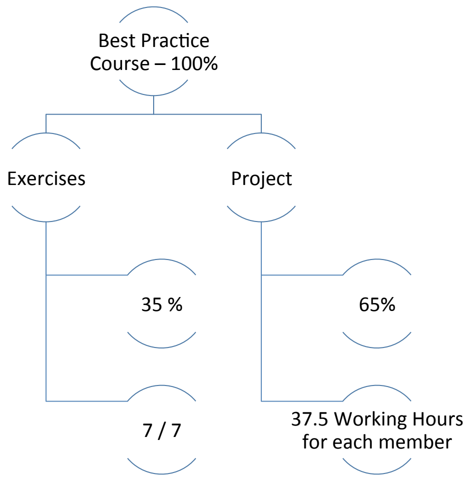
Grading

- **Grade:**
  - Exercises are prepared to be done in class
  - There is no grade for the exercises, just "Accepted/Non-accepted"
  - 7 Exercises accepted are equal to 35% of the final grade
  - If one or more exercise is missed, delivery until **Monday Morning (Sept 15th)**
  - Project is 65% of the grade
  - Project work consists of groups of 2 or 3 persons
  - It is expected 37.5 project hours for each of the group members



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Monday

Henrique Gaspar - Fall 2014
hega@hials.no - B410 (AMO)

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What is a System?

*A **system** is an interconnected set of elements that is coherently organized in a way that achieves something.*

If you look at that definition closely for a minute, you can see that a system must consist of three kinds of things: elements, interconnections, and a function or purpose

Meadows

What is a System?

1.4.4 System

"*A system is a complex unity formed of many often diverse parts subject to a common plan or serving a common purpose.*" (Mirriam-Webster 1981)

A system is a thing built from many other things, components, which interact for a common purpose. If an engineer is to define a system he must describe its context, its behavior or purpose, and its structure

Oliver

What is a System?

- The word «system» stems from the Greek word «systema» meaning an organized whole.
- Asbjørnsen (1992): A system is an assemblage of interacting elements, the performance of which shall ensure a required performance of the total system over its entire life cycle
- System thinking is deeply rooted in philosophy. Any collection of any interaction parts may be called a system, e.g. technical and social systems

Dahl

September 2009

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What is a System?

(INCOSE)

System: An integrated set of elements that accomplish a defined objective. These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements.

Dahl

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How to identify a System?

How to know whether you are looking at a system or just a bunch of stuff:

A) Can you identify parts?

… and…

B) Do the parts affect each other?

… and ….

C) Do the parts together produce an effect that is different from the effect of each part on its own?

… and perhaps …

D) Does the effect, the behavior over time, persist in a variety of circumstances?

Meadows

How to identify a System?

Systems Engineering

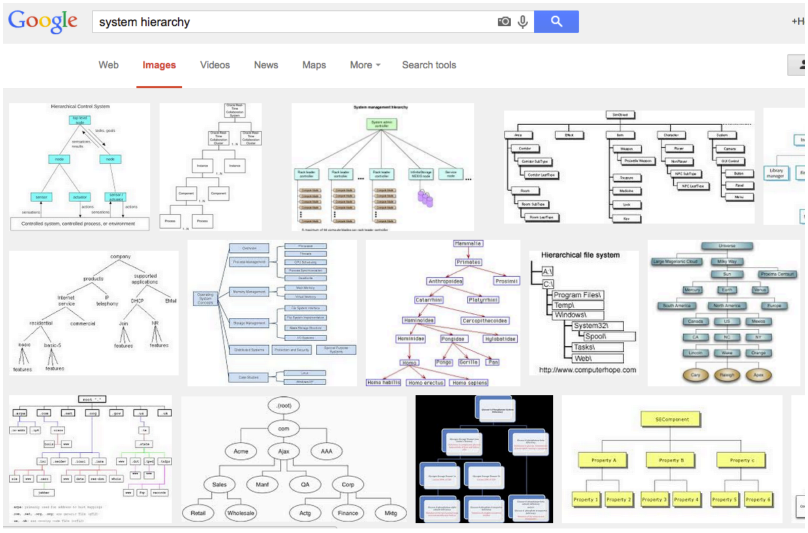
Systems engineering is a discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspect. (Ramo1)

Systems engineering is an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near optimal manner, the full range of requirements for the system. (Eisner2)

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, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. (INCOSE3)

Systems Hierarchy



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Systems Hierarchy

By a *hierarchic system,* or hierarchy, I mean a system that is composed of interrelated subsystems, each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary subsystem. In most systems in nature, it is somewhat arbitrary as to where we leave off the partitioning and what subsystems we take as elementary. Physics makes much use of the concept of "elementary particle," although particles have a disconcerting tendency not to remain elementary very long. Only a couple of generations ago, the atoms themselves were elementary particles; today, to the nuclear physicist they are complex systems. For certain purposes of astronomy, whole stars, or even galaxies, can be regarded as elementary subsystems. In one kind of biological research, a cell may be treated as an elementary subsystem; in another, a protein molecule; in still another, an amino acid residue.

Simon

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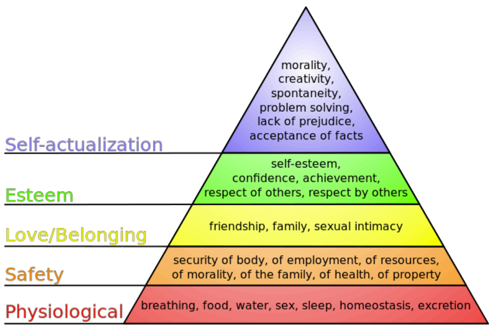
Systems Hierarchy

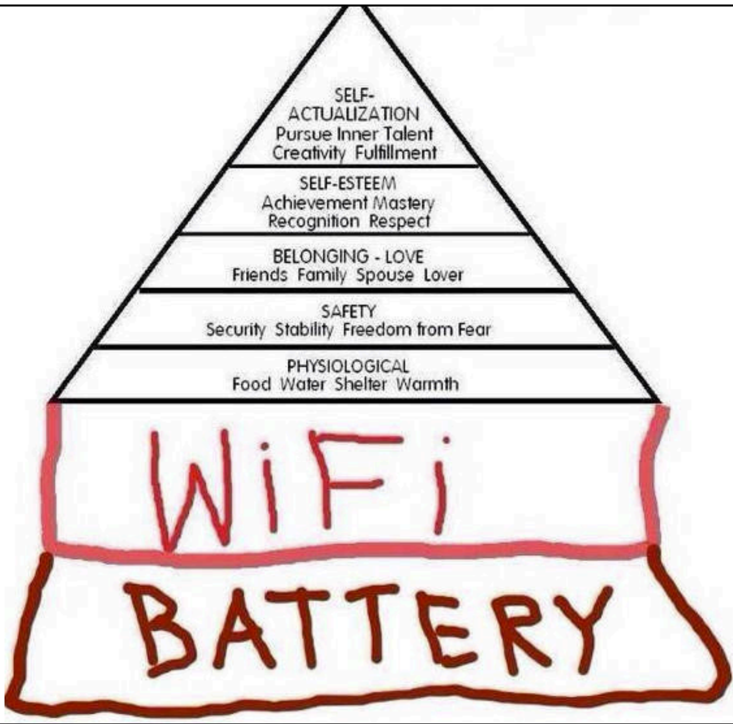
I have already given an example of one kind of hierarchy that is frequently encountered in the social sciences: a formal organization. Business firms, governments, universities all have a clearly visible parts-within-parts structure. But formal organizations are not the only, or even the most common, kind of social hierarchy. Almost all societies have elementary units called families, which may be grouped into villages or tribes, and these into larger groupings, and so on. If we make a chart of social interactions, of who talks to whom, the clusters of dense interaction in the chart will identify a rather well-defined hierarchic structure. The groupings in this structure may be defined operationally by some measure of frequency of interaction in this sociometric matrix.

Simon

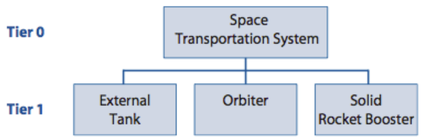
(other) Systems Hierarchy



Maslow's Hierarchy of Needs



Systems Hierarchy



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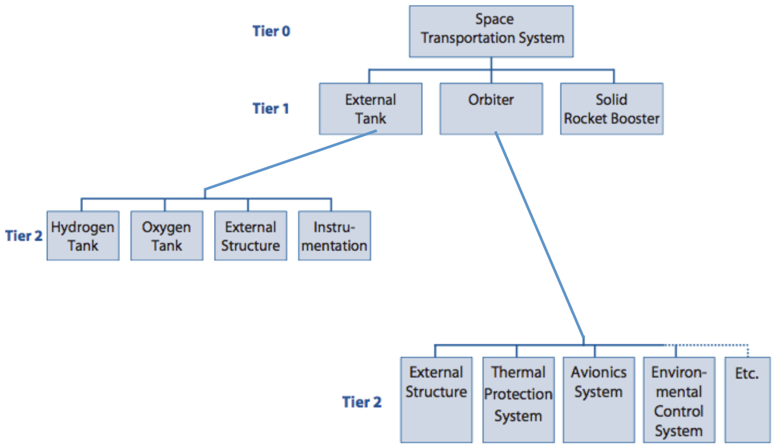
Systems Hierarchy



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Systems Hierarchy

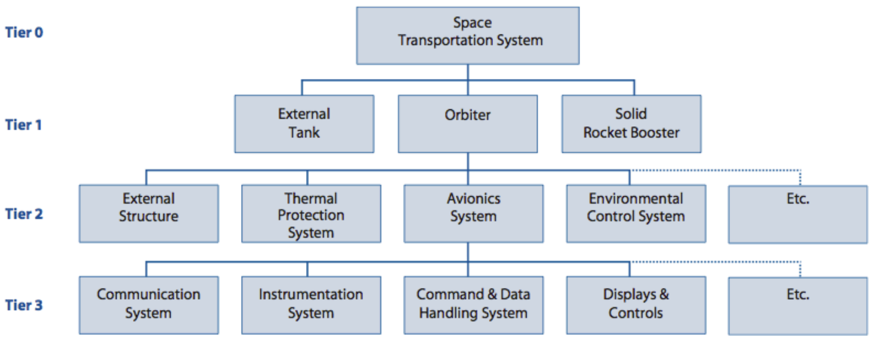

Figure 2.3-5 Product hierarchy, tier 3: avionics system

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Systems Hierarchy

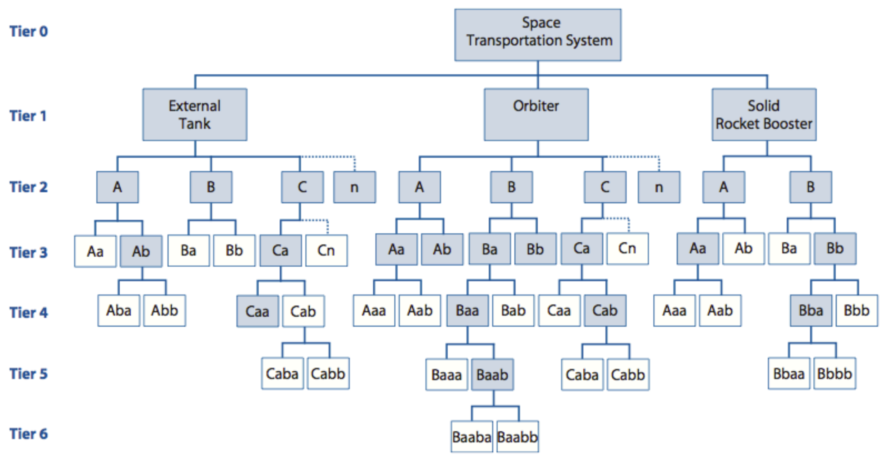

Figure 2.3-6 Product hierarchy: complete pass through system design processes side of the SE engine

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Systems Complexity

THE DESCRIPTION OF COMPLEXITY

If you ask a person to draw a complex object—such as a human face—he will almost always proceed in a hierarchic fashion.[20] First he will outline the face. Then he will add or insert features: eyes, nose, mouth, ears, hair. If asked to elaborate, he will begin to develop details for each of the features—pupils, eyelids, lashes for the eyes, and so on—until he reaches thelimitsof his anatomical knowledge. His information about the object is arranged hierarchically in memory, like a topical outline.

When information is put in outline form, it is easy to include information about the relations among the major parts and information about the internal relations of parts in each of the suboutlines. Detailed information about the relations of subparts belonging to different parts has no place in the outline and is likely to be lost. The loss of such information and the preservation mainly of information about hierarchic order is a salient characteristic that distinguishes the drawings of a child or someone untrained in representation from the drawing of a trained artist. (I am speaking of an artist who is striving for representation.)

https://www.youtube.com/watch?v=7kKJW8ZLcew

Simon

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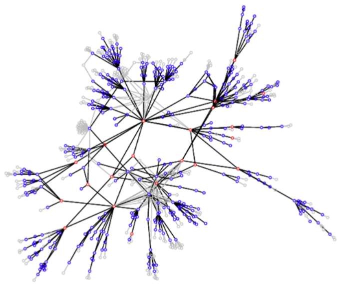
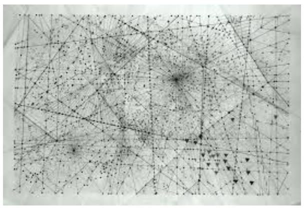
Systems Complexity

- Complexity as Size
- Complexity as Entropy
- Complexity as Algorithmic Information Content
- Complexity as Logical Depth
- Complexity as Thermodynamic Depth
- Complexity as Computational Capacity
- Statistical Complexity
- Complexity as Fractal Dimension
- Complexity as Degree of Hierarchy



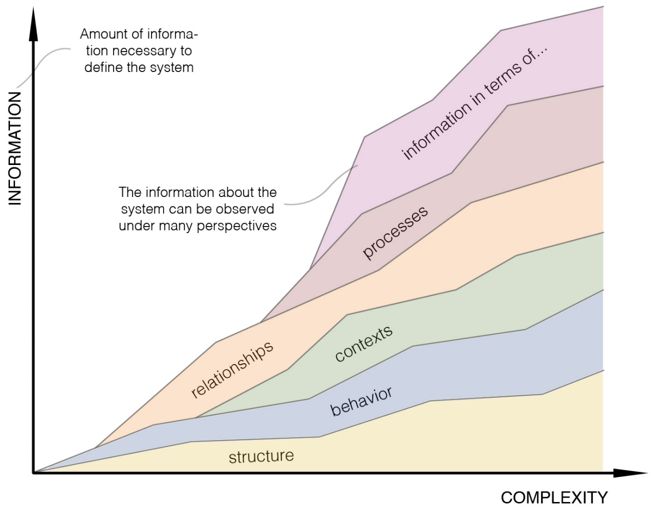


Mitchel

Systems Complexity

Degree of Complexity	Technical System	Characteristics	Examples
I (simplest)	part, component	elementary system produced without assembly operations	bolt, bearing sleeve, spring, washer
II	group, mechanism, subassembly	simple system that can fulfill some higher functions	gear box, hydraulic drive, spindle head, brake unit, shaft coupling
III	machine, apparatus, device	system that consists of sub-assembles and parts that perform a closed function	lathe, motor vehicle, electric motor
IV	plant, equipment, complex machine unit	complicated system that fulfills a number of functions and that consists of machines, groups and parts that constitute a functional and spatial unity	hardening plant, machining transfer line, factory equipment

Systems Complexity



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Decomposition and Encapsulation

- **Decomposition** simplifies the handling of a complex system by breaking core aspects into smaller chunks or parts (or assemblies, subsystems, classes) for better understanding of them and their mutual interactions, reducing information required to sufficiently (for the purpose) understand performance of the overall system.
- **Encapsulation** simplifies connection of parts with other parts, defining clear inputs/outputs. This process combines smaller parts into larger subsystems or assemblies, with predefined interfaces, thus reducing the number of interactions and the need for detailed information

Fundamentals

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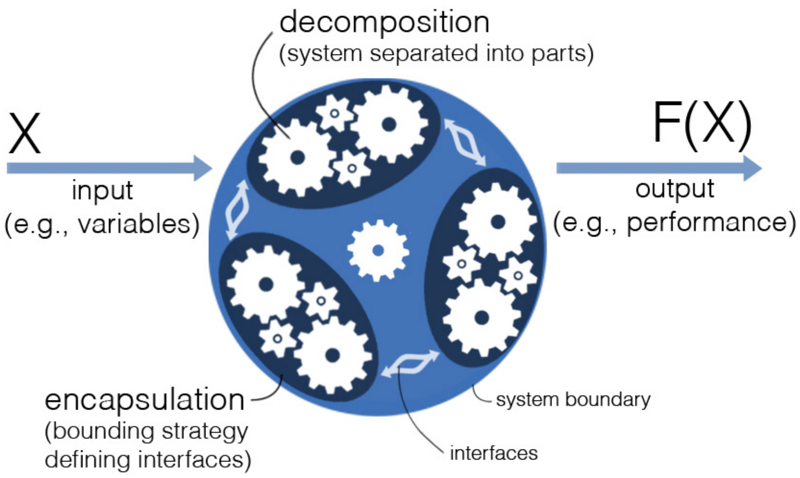
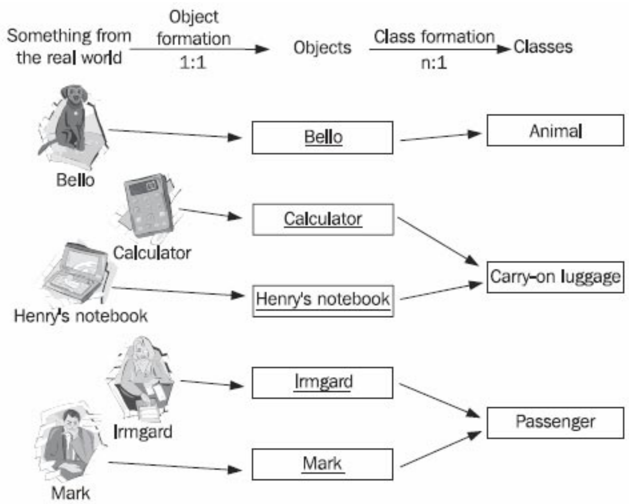
Decomposition and Encapsulation



Fundamentals

Classes and Objects



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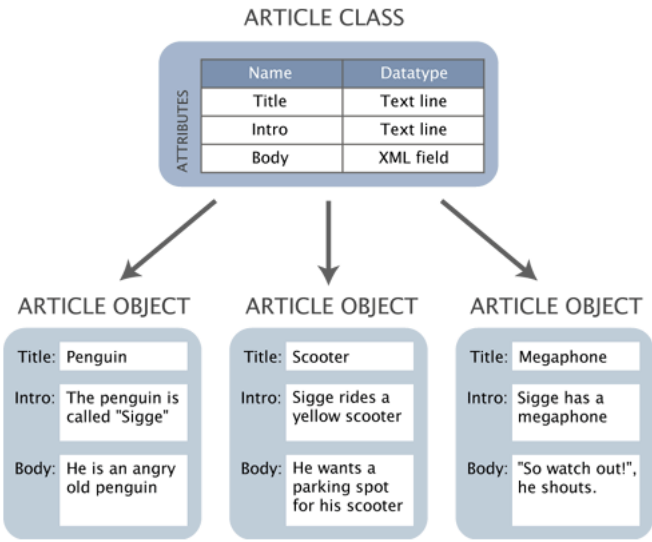
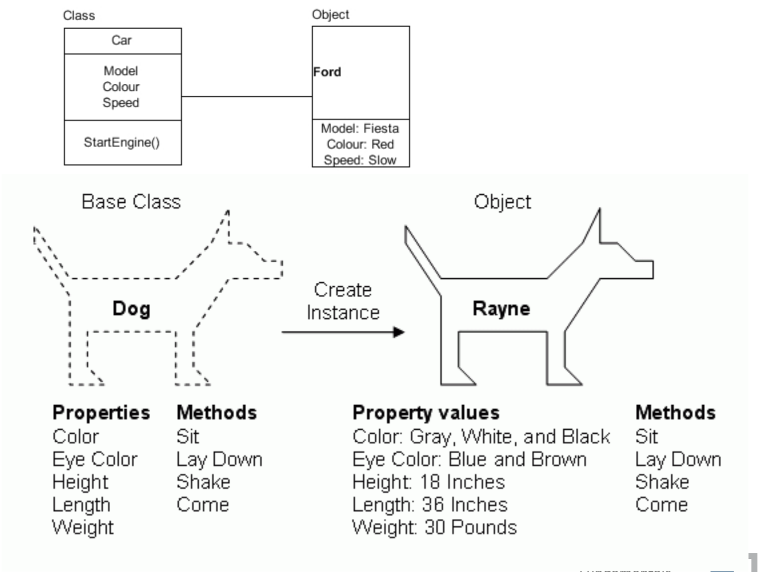
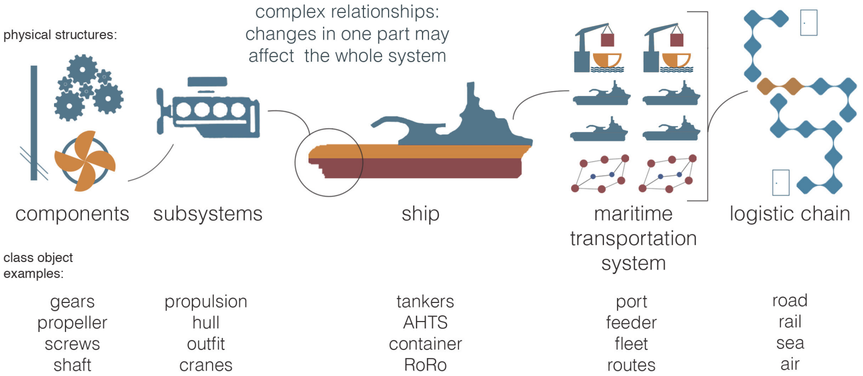


Classes and Objects

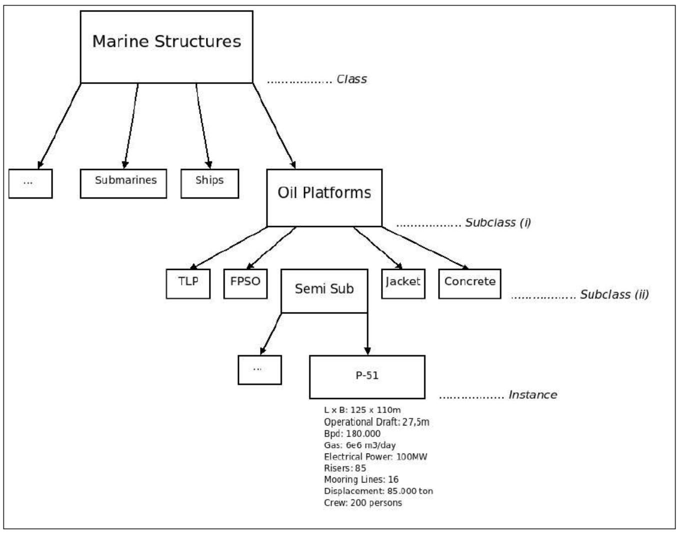


Maritime Example



Apply concepts in this system!

Maritime Example



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Exercise 01

1. **Pick a complex system around you and describe via Meadow's four questions:**
   a. Identify the parts
   b. How the parts affects each other?
   c. What are the effects/behavior of each part separately, and what effect is produced when they are combined?
   d. How the effect/behavior changes over time? In which Circumstances?
2. **Create an hierarchical structure for your system in 1), decomposing into classes, subclasses and objects/instances**
3. **Establish few main attributes for each component of your hierarchy**

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Design - Monday, Sept 8th

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Natural x Artificial Systems

- Inside the man-made terminology relies the main difference between the natural and artificial sciences: the purpose. The human being has the need of design something to achieve some purpose. In the natural sciences there is no intention; if something happens, just happens. Gravity is gravity, no mankind purpose in this. Even when the cause is know, Why the gravity happens? there is no purpose in the action (or task).

Fundamentals

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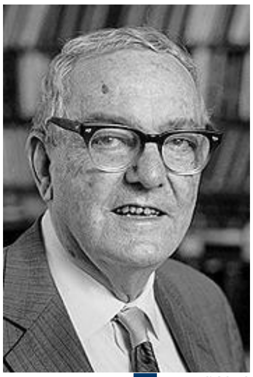
Natural x Artificial Systems

- The Artificial ~ synthesized by humans, as opposed to natural phenomena
- Artificial phenomena imitate nature
- "The Artificial" can be characterized by goals, intentions, functions, purpose – idea of a PURPOSE
- When studying a shoal of fish you are studying a system already put together. For the designer of a ship, or a fleet of vessels, it is putting it together in the first place that is the main intellectual challenge
- The idea of desired stage is the reason to someone design something. In the design has to be a change; and this change is also what differentiates the design task from other engineering tasks, like analysis.

Natural x Artificial Systems

- Hebert Simon, The Sciences of the Artificial, 3rd ed. MIT Press.
- Design is devising courses of action aimed at changing existing situations into preferred ones
- -> Vs. natural science: INTENTION
- -> Vs. Engineering anaysis: CHANGE
- (Reducing complexity)



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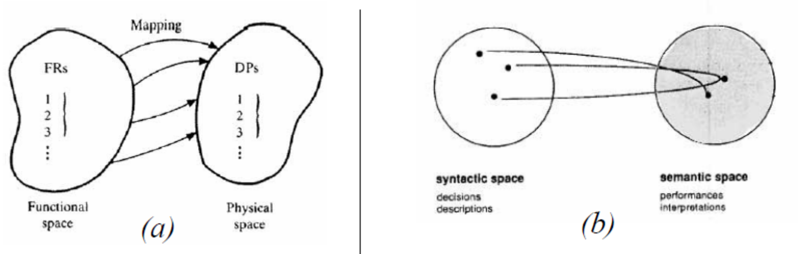
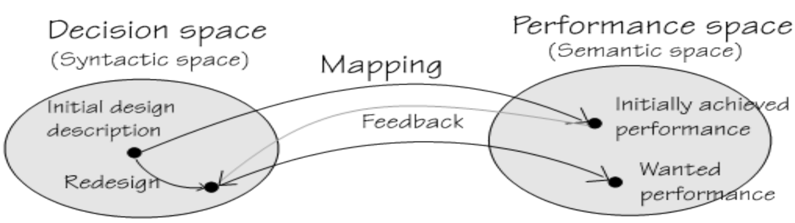
What is Design?

- Suh states that design is defined as the mapping process from the functional space to the physical state to satisfy the designer-specified functional requirements (a)
- Gero has a similar approach, when he represents the design task as mapping between a decision space and a performance space, where the design itself is a single point in the decision space (b)



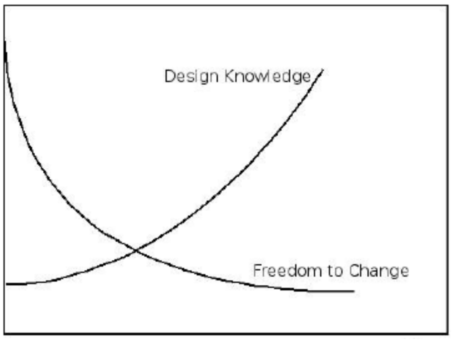
What is Design?



- (hull form & propeller) → (required SHP)
- (hull form) → (seakeeping behaviour)
- (hull form, propeller, machinery) → (ship speed)
- (all ship systems) → (total cost)

What is Design?

- The process of design, is different from the usual scientific approach. The idea of purpose add a lot of characteristics, such as time and cost constraints.



Fundamentals

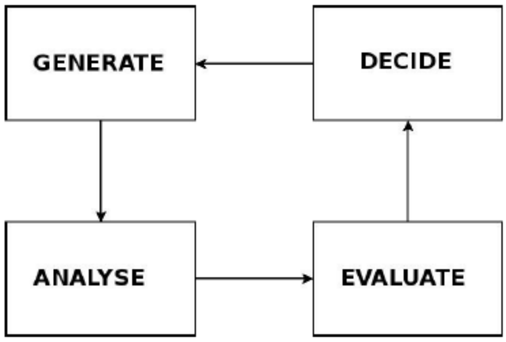
Design as an Abductive Process

Deduction	(1) case	+	(2) rule	→	(3) **result**
Induction	(1) case	+	(3) result	→	(2) **rule**
Abduction	(2) rule	+	(3) result	→	(1) **case**

- Deduction (m,a – F?)
- Induction (m/a, F – F = ma)
- Abduction (F = X, m =?, a=?)

Fundamentals

Basic Design Process



GENERATE one, or a set of, design description(s)

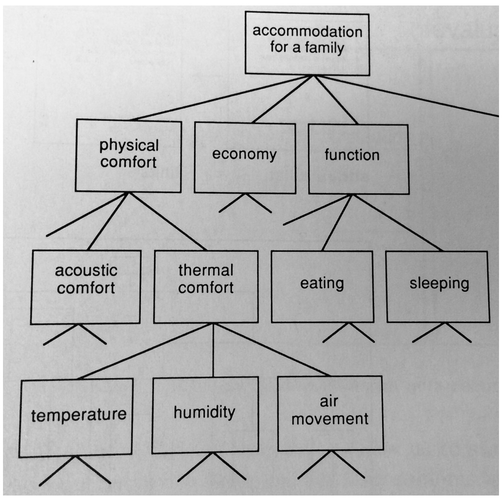
ANALYSE the description(s) to derive the relevant design performance(s)

EVALUATE the performances with respect to the design goals

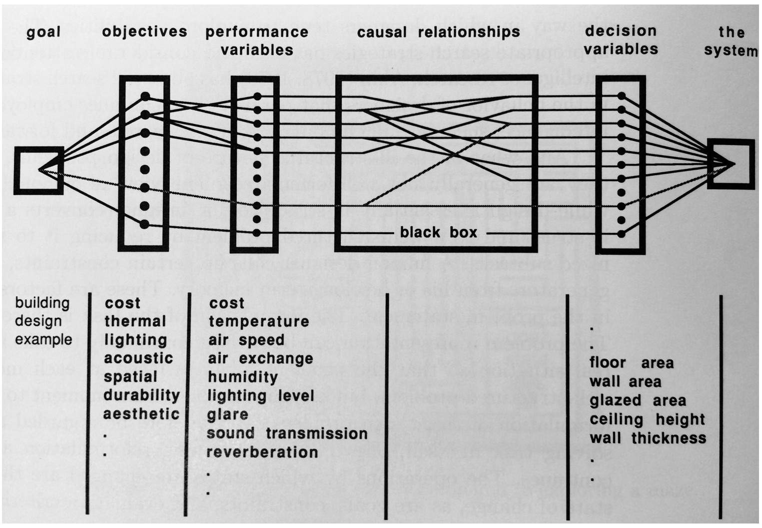
DECIDE whether the current best solution is acceptable, or whether it is necessary to generate additional design solutions

Goal Decomposition

Value decomposed in many criteria/key performance indicators (KPIs)



Extended Mapping

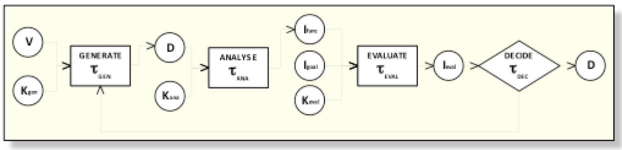


Design Domain (Ship Example)

- Complex mapping between form and function
- Multi-dimensional, partly non-monetary performance evaluation
- High cost of error
- Shallow knowledge structure
- Strong domain tradition
- Strict time and resource constraints on the design process
- Predominantly "one-of-a-kind" and "engineered-to-order" solutions

System Design Vocabulary

- The task observed in the design process are only able to be performed when the engineer has the descriptions of the design model.
- This description is produced from a vocabulary, and each type of design have a specific vocabulary to be able to describe the characteristics of the system. Only with a description in certain level is possible to Analyse and Evaluate.
- Examples:
  - Ship
  - Oil Platform
  - Fleet



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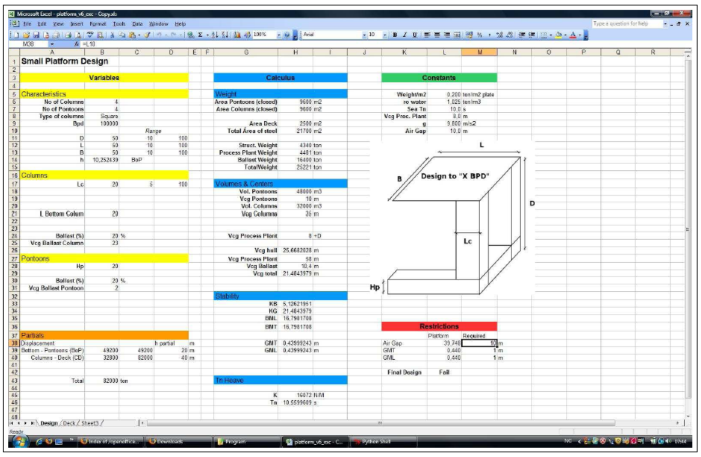
Approaches

- Search / Optimization



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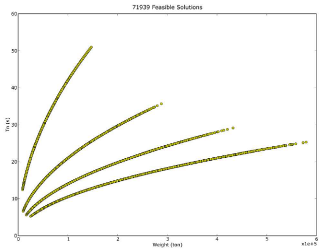
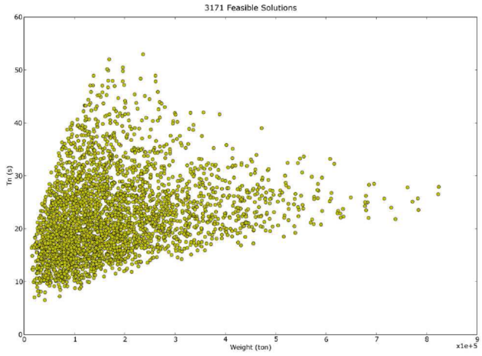
Approaches

- Search / Optimization





Approaches

- Axiomatic Design

$$\{FR\}_M = [A]_{MN} \cdot \{DP\}_N$$

Suh says that are two axioms that must be followed to achieve a good design: 1 - The Independence Axiom (maintain the independence of the FRs); 2 The Information Axiom (minimize the information content of the design). A discussion about those axioms, and how it leads to a good design has been done trough the class.

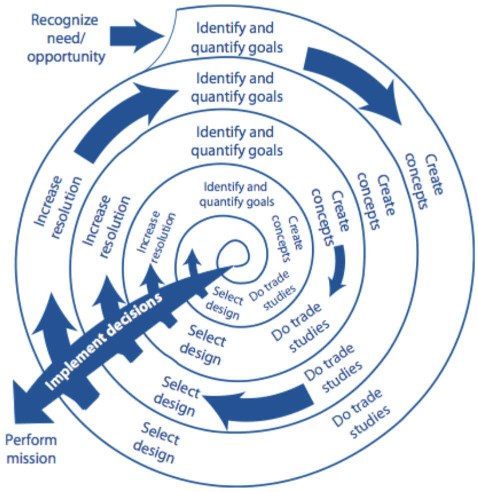
The first axiom is directly related to the three types of design listed by Suh: coupled, uncoupled and decoupled. The form of the matrix [A] for each one the types of design is represented in (2):

$$A = \begin{vmatrix} X & O & O \\ O & X & O \\ O & O & X \end{vmatrix} \qquad A = \begin{vmatrix} X & O & O \\ X & X & O \\ X & X & X \end{vmatrix} \qquad A = \begin{vmatrix} X & X & X \\ X & X & X \\ X & X & X \end{vmatrix} \quad (2)$$

uncoupled *decoupled* *coupled*

Approaches

- Systematic
- Relationship between levels
- Walk-through steps



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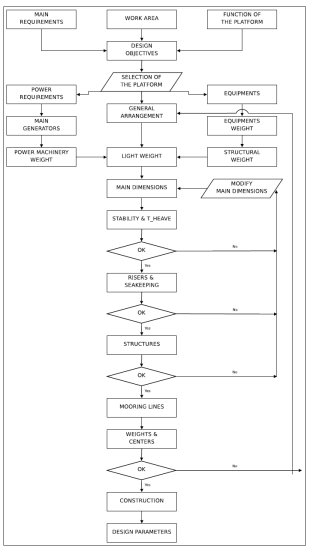
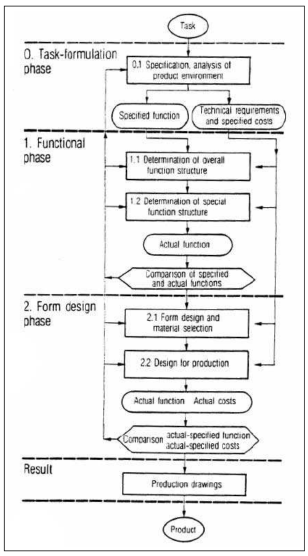
Systematic Design





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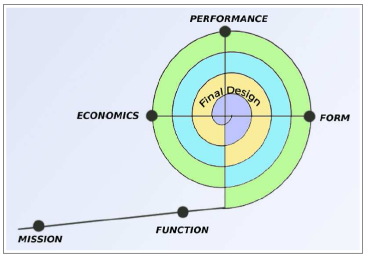
System Based Design

- In the traditional way, the designer has to make a large number of commitments in the early stages.
- The SBD approach is more focused in the functional requirements, allowing the development of the project in a functional way, without closing it into the beginning.
- In SBD, instead of starting with some values of design parameters - as L, B or D - and iterate it, the designer should first focus in what can generate some value to the system. The real core of the project has to be reached. For instance, passengers in a cruise vessel, storage capacity in a tanker or number of TEU's in a container ship.
- After the establishment of this core, the other systems will follow it, filling the necessary features to support the main function of the system.
- This more practical approach has as main idea the gain of more possible knowledge in the first stages and being able to keep the problem open time enough until the sufficient knowledge to solve it has been acquainted. When it occurs, there are the transformation from function to form.

System Based Design

0. Recognition of problems and possibilities
1. Fact Finding
2. Definition of the task and goals
3. Idea Finding
4. Select the best idea for refining
5. Acceptance & Implementation
6. Feedback and reward



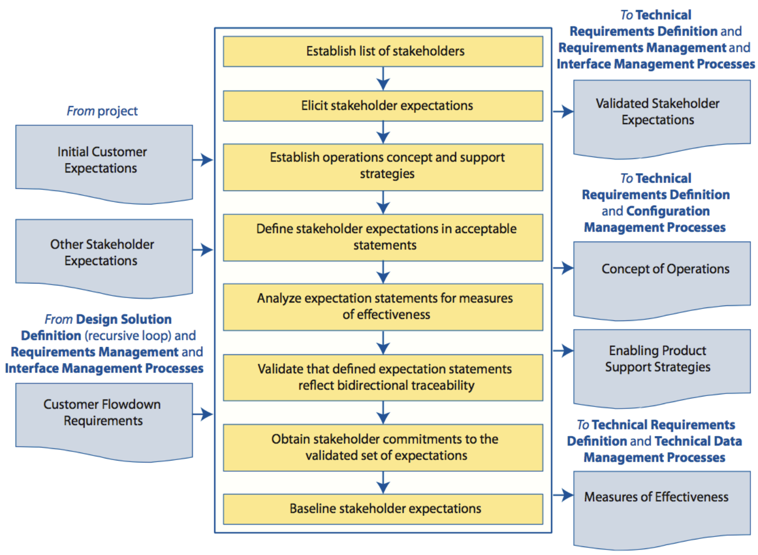
System Design Keys (NASA)

- Successfully understanding and defining the mission objectives and operational concepts are keys to capturing the stakeholder expectations, which will translate into quality requirements over the life cycle of the project.
- Complete and thorough requirements traceability is a critical factor in successful validation of requirements.
- Clear and unambiguous requirements will help avoid misunderstanding when developing the overall system and when making major or minor changes.
- Document all decisions made during the development of the original design concept in the technical data package. This will make the original design philosophy and negotiation results available to assess future proposed changes and modifications against.

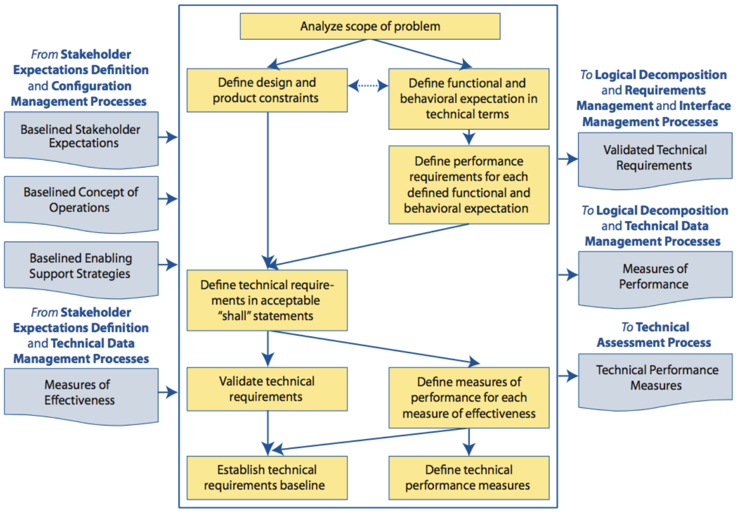
- The design solution verification occurs when an acceptable design solution has been selected and documented in a technical data package. The design solution is verified against the system requirements and constraints. However, the validation of a design solution is a continuing recursive and iterative process during which the design solution is evaluated against stakeholder expectations.

1. Stakeholder Expectations
2. Technical Requirements
3. Logical Decomposition
4. Design Solution Definition

Stakeholder Expectations Definition



Technical Requirements Definition



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Technical Requirements Definition

Example of Functional and Performance Requirements

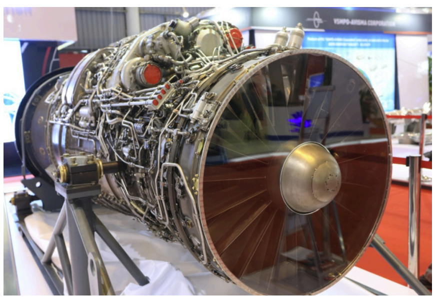
Initial Function Statement

The Thrust Vector Controller (TVC) shall provide vehicle control about the pitch and yaw axes.

This statement describes a high-level function that the TVC must perform. The technical team needs to transform this statement into a set of design-to functional and performance requirements.

Functional Requirements with Associated Performance Requirements

- The TVC shall gimbal the engine a maximum of 9 degrees, ± 0.1 degree.
- The TVC shall gimbal the engine at a maximum rate of 5 degrees/second ± 0.3 degrees/second.
- The TVC shall provide a force of 40,000 pounds, ± 500 pounds.
- The TVC shall have a frequency response of 20 Hz, ± 0.1 Hz.



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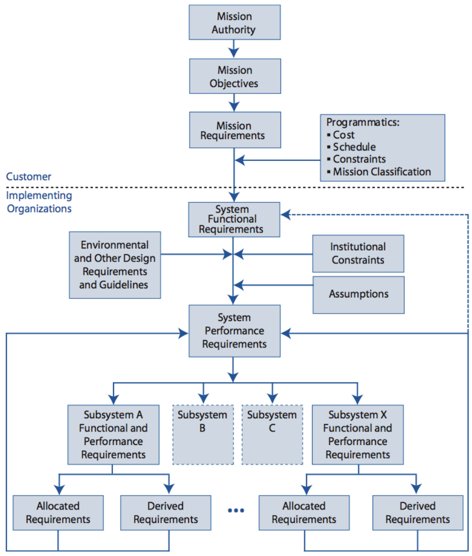
Technical Requirements Definition



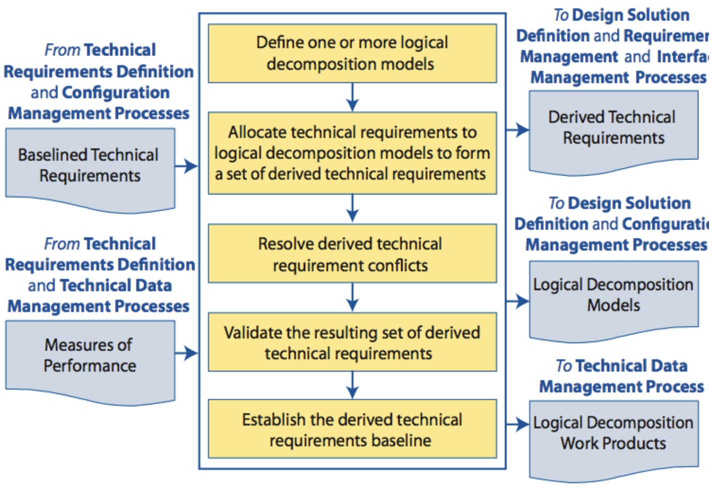
Item	Function
Requirement ID	Provides a unique numbering system for sorting and tracking.
Rationale	Provides additional information to help clarify the intent of the requirements at the time they were written. (See "Rationale" box below on what should be captured.)
Traced from	Captures the bidirectional traceability between parent requirements and lower level (derived) requirements and the relationships between requirements.
Owner	Person or group responsible for writing, managing, and/or approving changes to this requirement.
Verification method	Captures the method of verification (test, inspection, analysis, demonstration) and should be determined as the requirements are developed.
Verification lead	Person or group assigned responsibility for verifying the requirement.
Verification level	Specifies the level in the hierarchy at which the requirements will be verified (e.g., system, subsystem, element).

Rationale

The rationale should be kept up to date and include the following information:

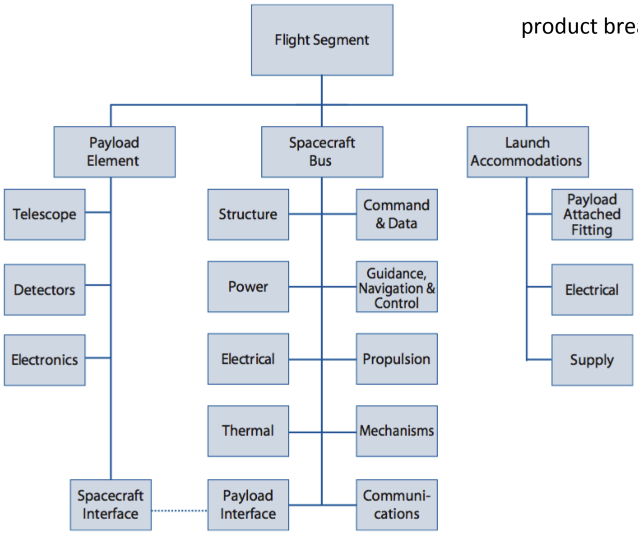
- **Reason for the Requirement:** Often the reason for the requirement is not obvious, and it may be lost if not recorded as the requirement is being documented. The reason may point to a constraint or concept of operations. If there is a clear parent requirement or trade study that explains the reason, then reference it.
- **Document Assumptions:** If a requirement was written assuming the completion of a technology development program or a successful technology mission, document the assumption.
- **Document Relationships:** The relationships with the product's expected operations (e.g., expectations about how stakeholders will use a product). This may be done with a link to the ConOps.
- **Document Design Constraints:** Imposed by the results from decisions made as the design evolves. If the requirement states a method of implementation, the rationale should state why the decision was made to limit the solution to this one method of implementation.

Logical Decomposition

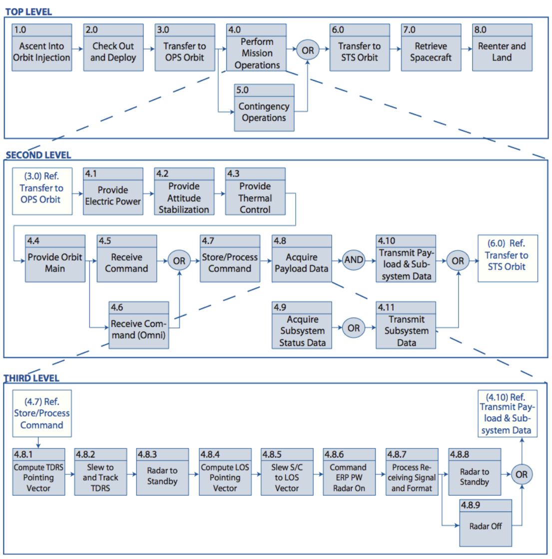


Logical Decomposition

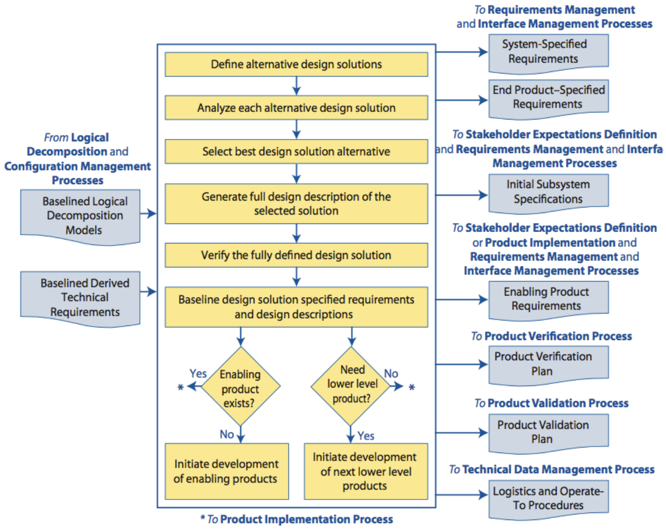
product breakdown structure



Logical Decomposition



Design Solution Definition



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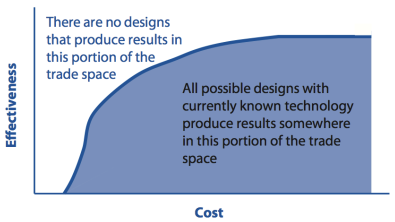
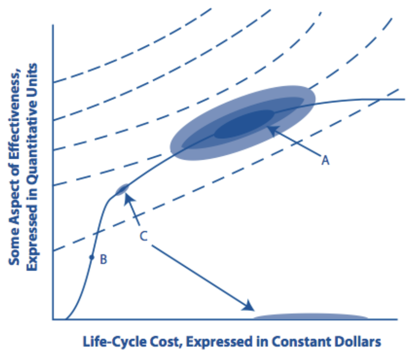
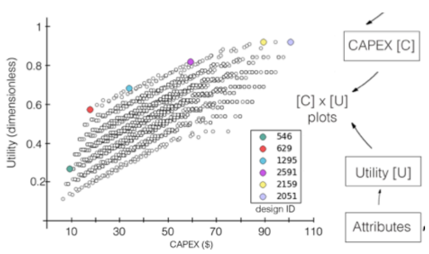
Design Solution Definition







Fundamentals

Exercise 02

1. **Based on an artificial system of your choice, to be carried on during the rest of the week:**
    a. Present a "goal decomposition" for your system, establishing a list of requirements
    b. Present the hierarchic structure of your system in 3 levels
    c. Identify the main "Form-Function" relationship for each of the levels, in connection with the idea of "purpose"
    d. Connect the "Functions" in *c* with your "Goals/ Requirements" in *a*. How these goals/requirements can be measured?

2. **Create few "pseudo-designs" for your system, based on Erikstad's Basic Design Process. Can you rank their performance?**

IP504914 System engineering
Best Practice Module

Week 37 – Classes Plan

Henrique Gaspar - Fall 2014
hega@hials.no - B410 (AMO)

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Lifecycle - Tuesday, Sept 9th

- **Morning:**
  - Lifecycle Characteristics
  - Decision Gates
  - Lifecycle stages
    - Pre-concept
    - Concept
    - Development
    - Production
    - Operation
    - Support
    - Retirement
  - Value Chain Overview
  - System Lifecycle Properties (Ilities)
- **Exercise:**
  - Propose a lifecycle for your system
  - Apply basic lifecycle method
  - Brief discussion on layers and boundaries

Literature:

1. INCOSE, "Systems Engineering Handbook", 2010
2. Haskins, C., "Systems Engineering Handbook – A guide for Lifecycle Processes and Activities", 2006
3. Ulstein, T., and Brett, P. O. "Critical systems thinking in ship design approaches." International Maritime Design Conference - Glasgow (2012).
4. NASA "Systems Engineering Handbook", 2007.
5. Ross et all "System Lifecycle Properties", SEARI-MIT, 2012

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Lifecycle Introduction

- Every artificial system has a lifecycle, even if not formally defined
- The life cycle processes and activities are selected, tailored as appropriate, and employed in a stage to fulfill the purpose and outcomes of that stage
- The purpose in defining the system life cycle is to establish a framework for meeting the stakeholders' needs in an orderly and efficient manner
- Systems engineering tasks are usually concentrated at the beginning of the life cycle, but both commercial and government organizations recognize the need for systems engineering throughout the systems life span

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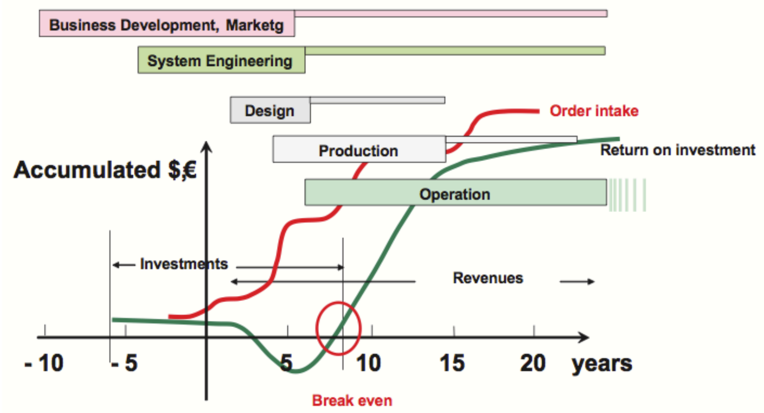
Lifecycle Characteristics

- Business Aspect (case)
- Budget Aspect (funding)
- Technical Aspect (product)



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Lifecycle Stages

LIFE CYCLE STAGES	PURPOSE	DECISION GATES
CONCEPT	*Identify stakeholders' needs* *Explore concepts* *Propose viable solutions*	*Decision Options* *– Execute next stage* *– Continue this stage* *– Go to a preceding stage* *– Hold project activity* *– Terminate project*
DEVELOPMENT	*Refine system requirements* *Create solution description* *Build system* *Verify and validate system*	
PRODUCTION	Produce systems Inspect and test [verify]	
UTILIZATION	*Operate system to satisfy users' needs*	
SUPPORT	*Provide sustained system capability*	
RETIREMENT	*Store, archive, or dispose of the system*	

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Lifecycle Stages

	infancy	adolescence	mature	ageing
driving factor	business vision		stable business model	harvesting of assets
value from	responsiveness	features	refinements / service	refining existing assets
requirements	discovery	select strategic	prioritise	low effort high value only
dominant technical concerns	feasibility	scaling	legacy obsolescence	Lack of product know-how Low effort for obsolete technologies
type of people	inventors& pioneers	few inventors& pioneers "designers"	"engineers"	"maintainers"
process	chaotic		bureaucratic	budget driven
dominant pattern	over-dimensioning	conservative expansion	mid-life refactoring	UI gadgets

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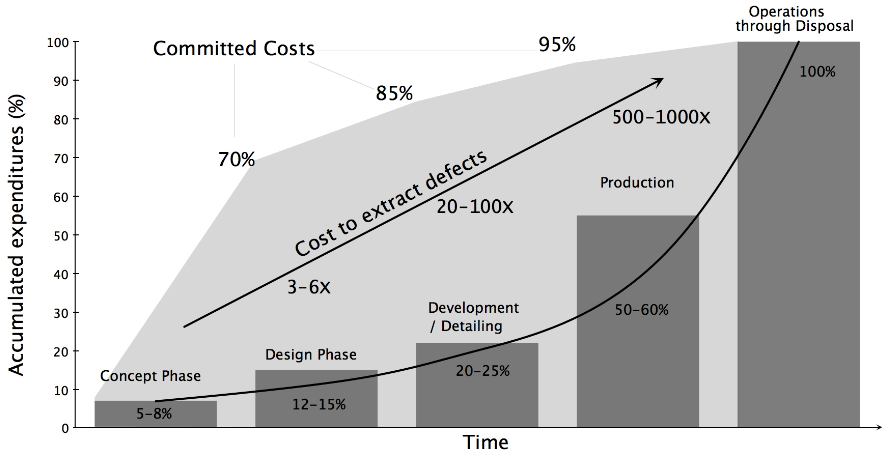
Lifecycle Characteristics



What costs should be counted?

How should costs occurring at different times be treated?

What about costs that cannot easily be measured in $$$?

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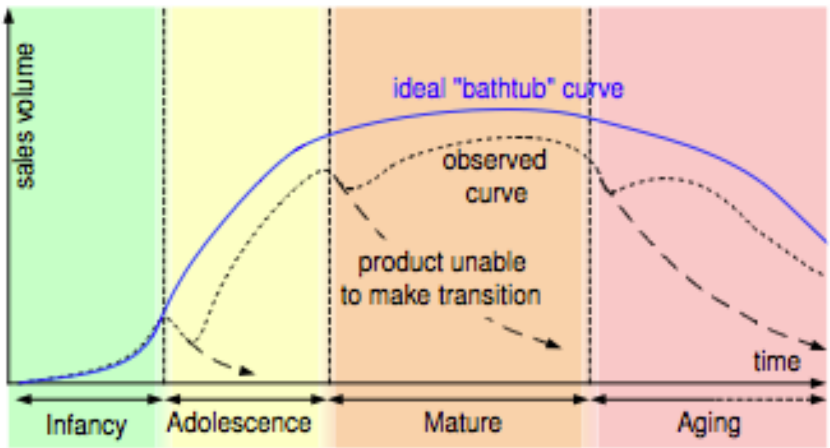
Lifecycle Characteristics



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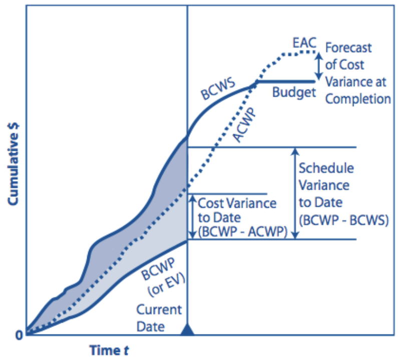
Lifecycle Costs Considerations

- Identify a common set of ground rules and assumptions for life-cycle cost estimation
- Manage to a cost baseline and maintain traceability to the technical baseline with documentation for subsequent cost changes;
- Ensure that best-practice methods, tools, and models are used for life-cycle cost analysis
- Track the estimated life-cycle cost throughout the project life cycle; *and, most important:*
- Integrate life-cycle cost considerations into the design and development process via trade studies and formal change request assessments.



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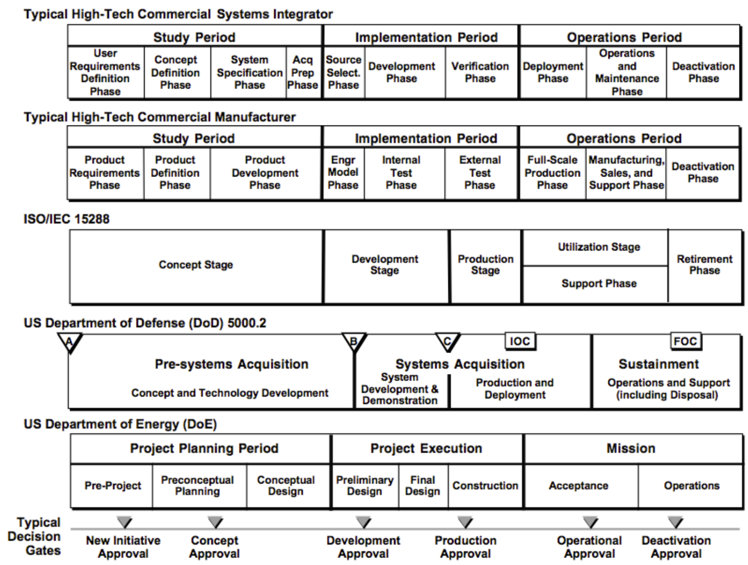
Lifecycle Examples



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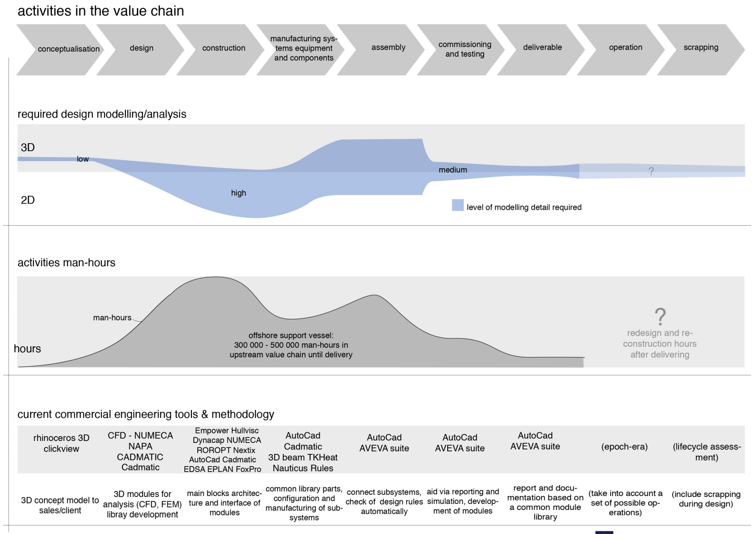
Maritime Example



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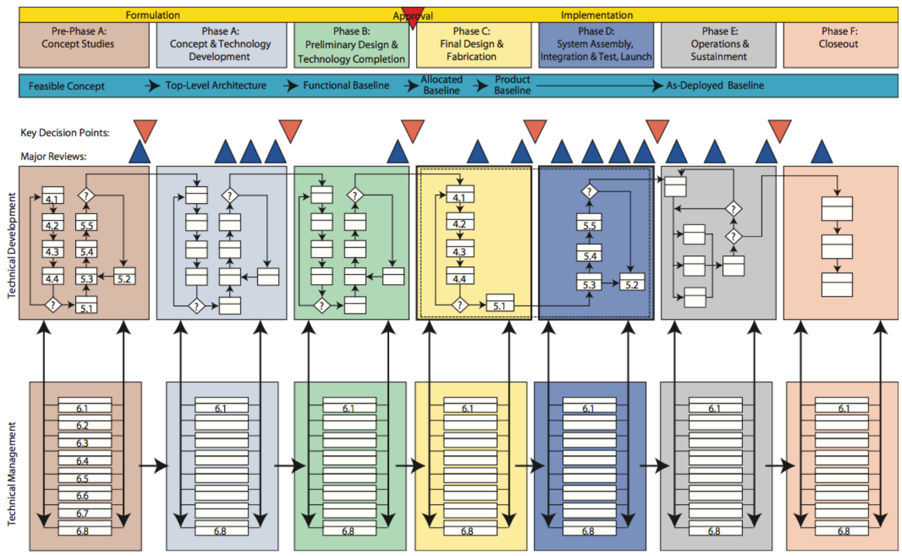
NASA Example



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Phases

	Phase	Purpose	Typical Output
Formulation	Pre-Phase A Concept Studies	To produce a broad spectrum of ideas and alternatives for missions from which new programs/projects can be selected. Determine feasibility of desired system, develop mission concepts, draft system-level requirements, identify potential technology needs.	Feasible system concepts in the form of simulations, analysis, study reports, models, and mockups
Formulation	Phase A Concept and Technology Development	To determine the feasibility and desirability of a suggested new major system and establish an initial baseline compatibility with NASA's strategic plans. Develop final mission concept, system-level requirements, and needed system structure technology developments.	System concept definition in the form of simulations, analysis, engineering models, and mockups and trade study definition
Formulation	Phase B Preliminary Design and Technology Completion	To define the project in enough detail to establish an initial baseline capable of meeting mission needs. Develop system structure end product (and enabling product) requirements and generate a preliminary design for each system structure end product.	End products in the form of mockups, trade study results, specification and interface documents, and prototypes
Implementation	Phase C Final Design and Fabrication	To complete the detailed design of the system (and its associated subsystems, including its operations systems), fabricate hardware, and code software. Generate final designs for each system structure end product.	End product detailed designs, end product component fabrication, and software development
Implementation	Phase D System Assembly, Integration and Test, Launch	To assemble and integrate the products to create the system, meanwhile developing confidence that it will be able to meet the system requirements. Launch and prepare for operations. Perform system end product implementation, assembly, integration and test, and transition to use.	Operations-ready system end product with supporting related enabling products
Implementation	Phase E Operations and Sustainment	To conduct the mission and meet the initially identified need and maintain support for that need. Implement the mission operations plan.	Desired system
Implementation	Phase F Closeout	To implement the systems decommissioning/disposal plan developed in Phase E and perform analyses of the returned data and any returned samples.	Product closeout

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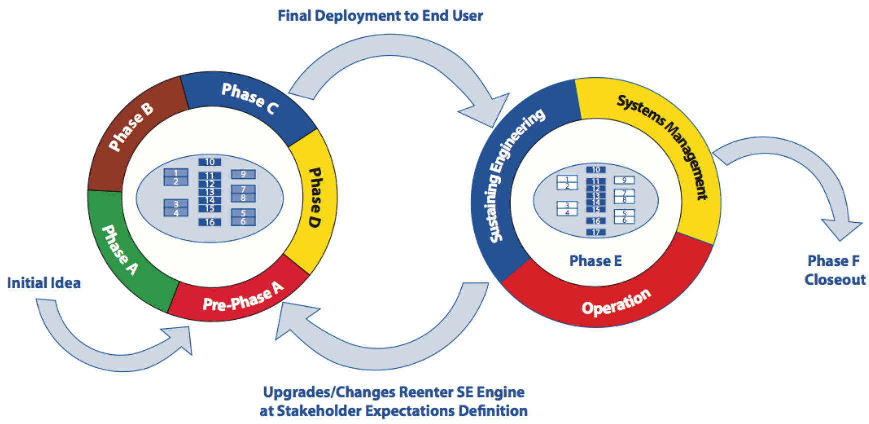
Phases



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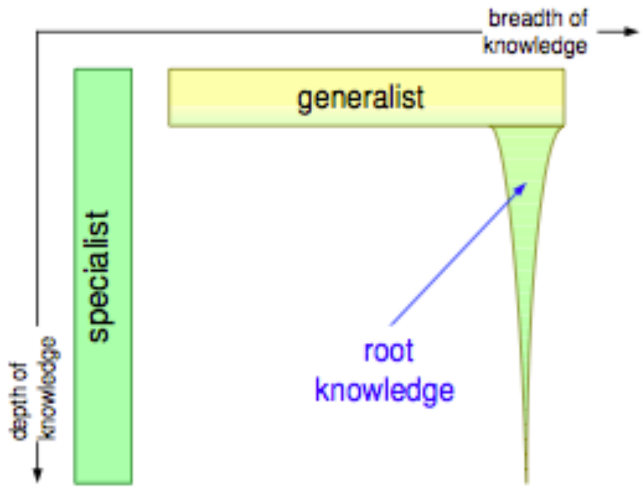
Generalist *vs* Specialist



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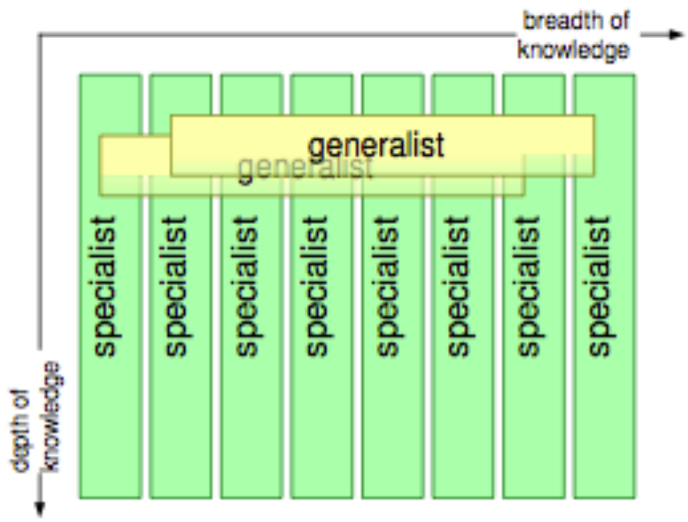
Generalist *vs* Specialist



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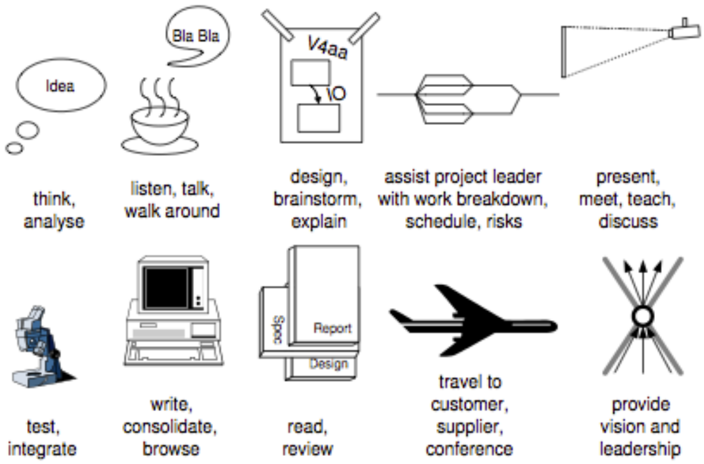
Generalist *vs* Specialist



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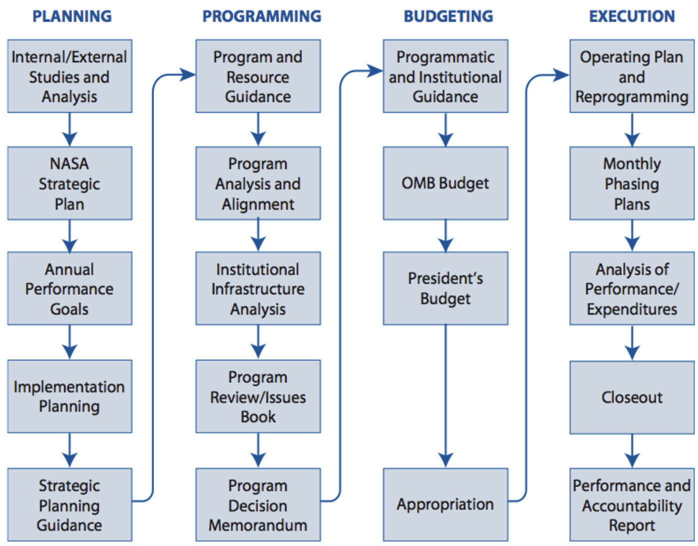
Budget



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System Lifecycle Properties

- Complex Engineering Systems live for decades or centuries
- The ilities are desired properties of systems, such as flexibility or maintainability (usually but not always ending in “ility”) that often manifest themselves after a system has been put to initial use.
- These properties are usually not the primary functional requirements of a system’s performance, but typically concern wider system impacts with respect to time and stakeholders than embodied in those primary functional requirements

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System Lifecycle Properties

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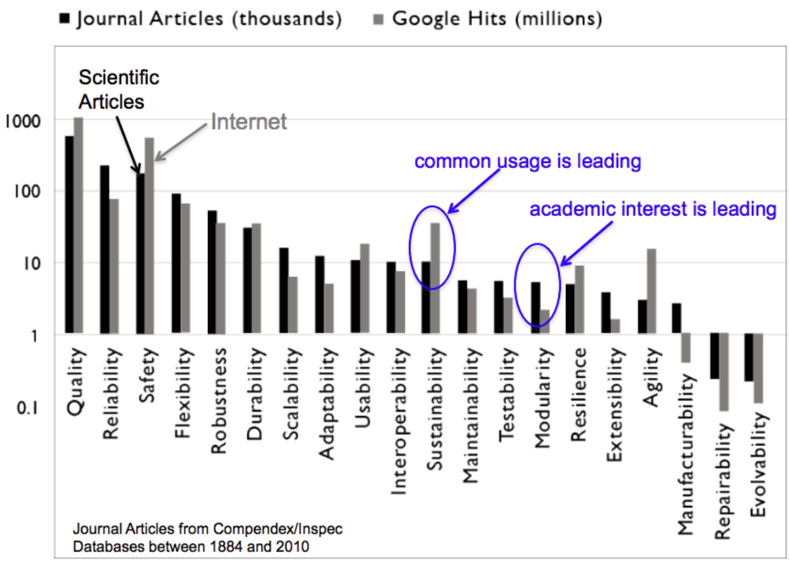

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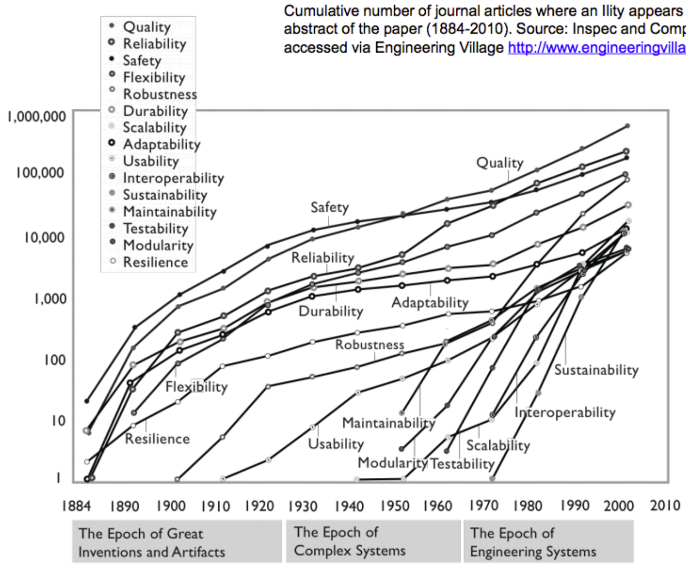
System Lifecycle Properties

Cumulative number of journal articles where an Ility appears in the title or abstract of the paper (1884-2010). Source: Inspec and Compendex, accessed via Engineering Village http://www.engineeringvillage.com

Fig. 4-2



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System Lifecycle Properties

Ility Name	Definition ("ability of a system…")
adaptability	to be changed by a system-internal change agent with intent
agility	to change in a timely fashion
changeability	to alter its operations or form, and consequently possibly its function, at an acceptable level of resources
evolvability	design to be inherited and changed across generations (over time)
extensibility	to accommodate new features after design
flexibility	to be changed by a system-external change agent with intent
interoperability	to effectively interact with other systems
modifiability	to change the current set of specified system parameters
modularity	degree to which a system is composed of modules (not an ability-type ility)
reconfigurability	to change its component arrangement and links reversibly
robustness	to maintain its level and/or set of specified parameters in the context of changing system external and internal forces
scalability	to change the current level of a specified system parameter
survivability	to minimize the impact of a finite duration disturbance on value delivery
value robustness	to maintain value delivery in spite of changes in needs or context
versatility	to satisfy diverse needs for the system without having to change form (measure of latent value)

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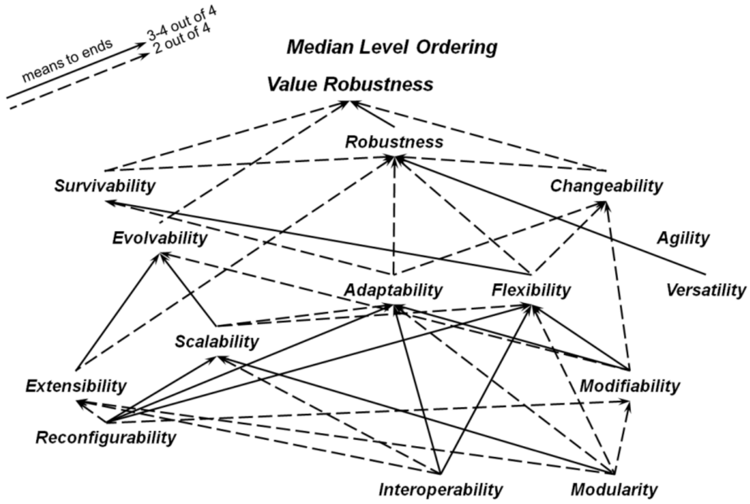
System Lifecycle Properties



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Exercise 03

1. **Present a Lifecycle for your System from yesterday:**
   a. What are the main stages and gates?
   b. Describe the purpose and typical output of each level
   c. Describe the level of detailing for each cycle
   d. How would you estimate a budget for your system?

2. **Based on the concept of "ilities":**
   a. Describe how to create and maintain value robustness for your system during its life cycle
   b. Decompose your value robustness in few "ilities" and describe how they affect the value perceived

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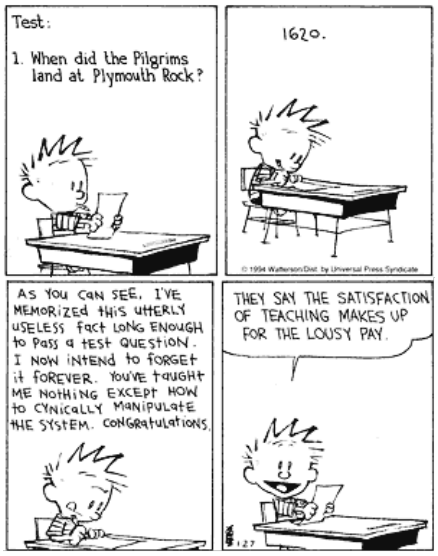
Product and Process
Tuesday, Sept 9th

- **Afternoon:**
  - Product and Process
  - Flowing through the system
  - System Architecture Process
  - Product Creation Process
  - Basic sources for process managements
  - Examples
- **Exercise:**
  - Product / Process distinction
  - Decomposing your process
  - Product flow through process
  - Establish form/function criteria

Literature:

1. Meadows, D. "Systems Thinking", 2014
2. INCOSE, "Systems Engineering Handbook", 2010
3. Muller, G. "System Architecting", 2010
4. PMBOOK, "Project Management Body of Knowledge"
5. Michael, J. "Systems Approaches to Management", 2000

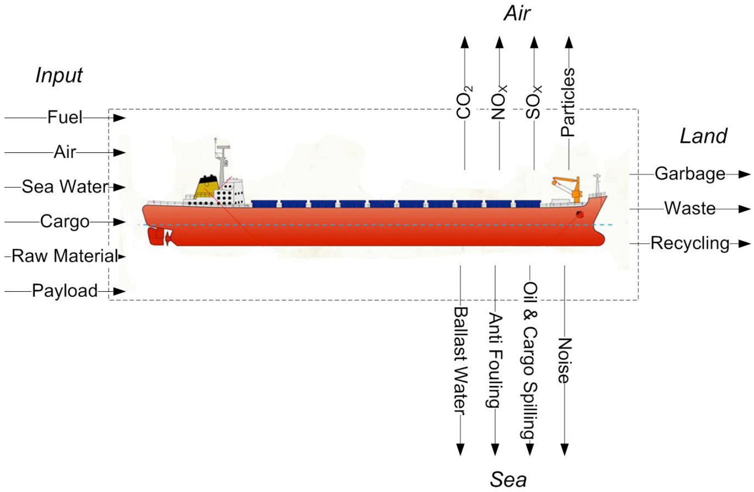
Manipulating the System



To:
manage, influence, control, handle, use, adapt, change, examine, hold, test, verify, act, pick up, deal, employ, direct, govern, conduct...

Fundamentals

Basic System Overview



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Process Definition

A process is an activity which takes place over time and which has a precise aim regarding the result to be achieved. The concept of a process is hierarchical which means that a process may consist of a partially ordered set of subprocesses.

Muller

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Process Attributes

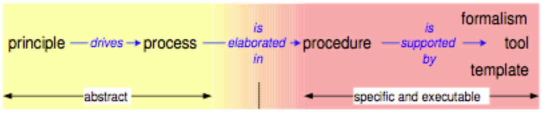
Purpose What is to be achieved and why

Structure How will the goal be achieved

Rationale What is the reasoning behind this process

Roles What roles are present, what responsibilities are associated, what incentives are present, what are the criteria for these roles

Ordering What phasing or sequence is applied



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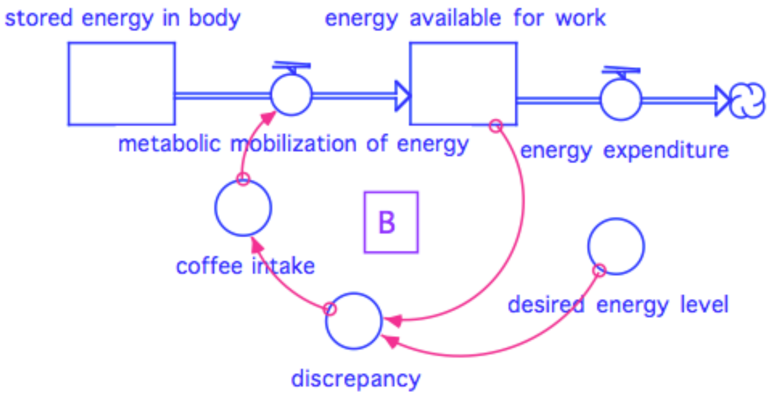
Basic System Process

Coffee intake



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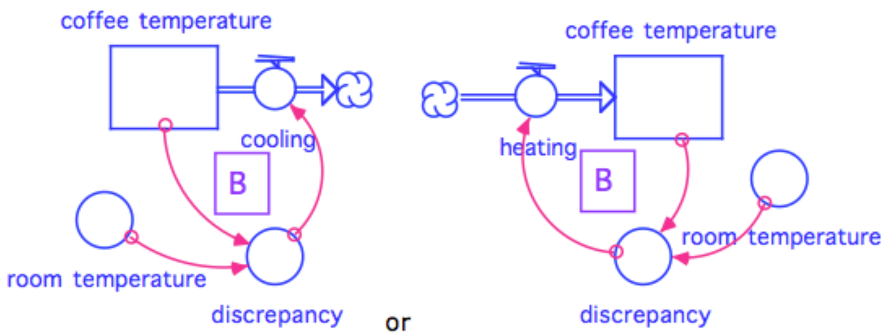
Basic System Process

Coffee temperature



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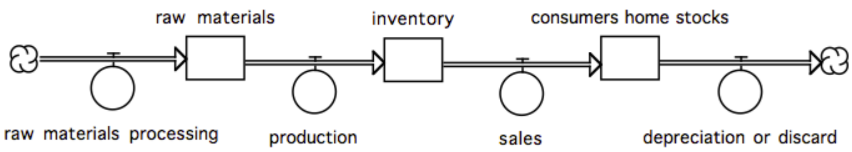
Basic Production Process

Production Process



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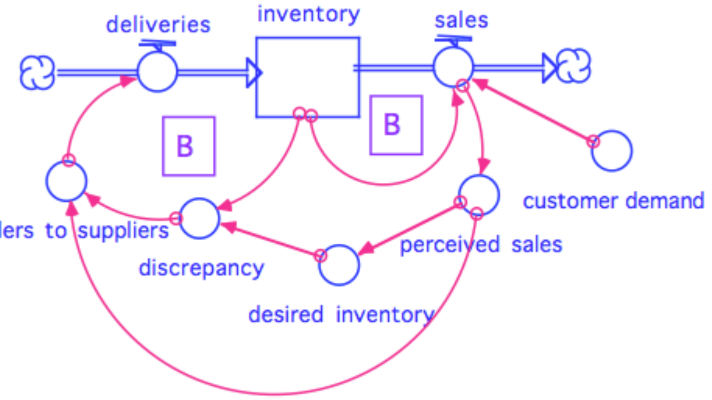
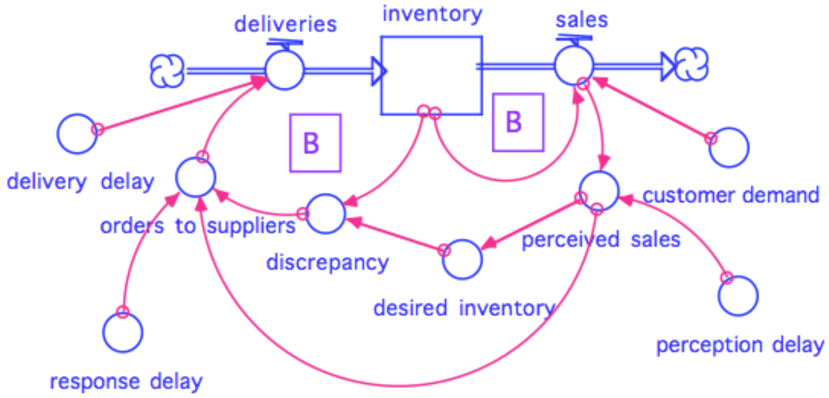
Basic System Process

inventory

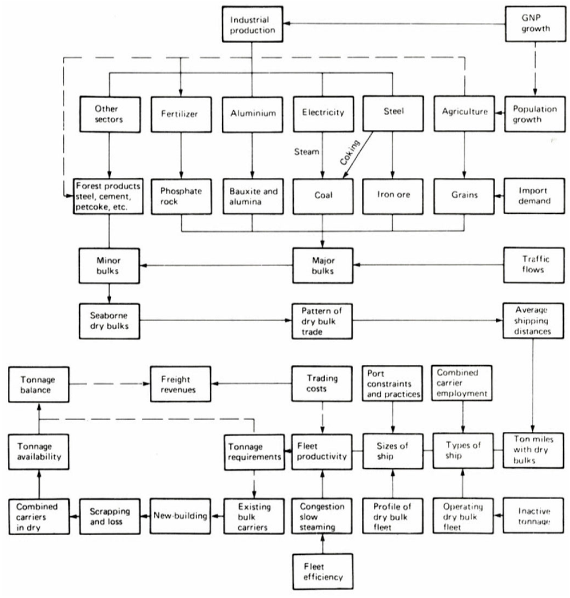


Basic System Process

inventory with delays



(not so) Basic System



Fleet & Ship

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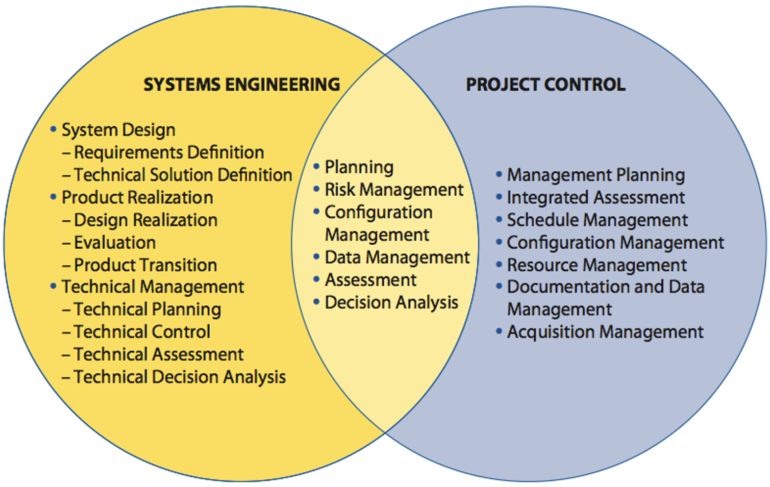
Process: SE and Project Control



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Process and Product for each Lifecycle Phase

	Phase	Purpose	Typical Output
Formulation	Pre-Phase A Concept Studies	To produce a broad spectrum of ideas and alternatives for missions from which new programs/projects can be selected. Determine feasibility of desired system, develop mission concepts, draft system-level requirements, identify potential technology needs.	Feasible system concepts in the form of simulations, analysis, study reports, models, and mockups
Formulation	Phase A Concept and Technology Development	To determine the feasibility and desirability of a suggested new major system and establish an initial baseline compatibility with NASA's strategic plans. Develop final mission concept, system-level requirements, and needed system structure technology developments.	System concept definition in the form of simulations, analysis, engineering models, and mockups and trade study definition
Formulation	Phase B Preliminary Design and Technology Completion	To define the project in enough detail to establish an initial baseline capable of meeting mission needs. Develop system structure end product (and enabling product) requirements and generate a preliminary design for each system structure end product.	End products in the form of mockups, trade study results, specification and interface documents, and prototypes
Implementation	Phase C Final Design and Fabrication	To complete the detailed design of the system (and its associated subsystems, including its operations systems), fabricate hardware, and code software. Generate final designs for each system structure end product.	End product detailed designs, end product component fabrication, and software development
Implementation	Phase D System Assembly, Integration and Test, Launch	To assemble and integrate the products to create the system, meanwhile developing confidence that it will be able to meet the system requirements. Launch and prepare for operations. Perform system end product implementation, assembly, integration and test, and transition to use.	Operations-ready system end product with supporting related enabling products
Implementation	Phase E Operations and Sustainment	To conduct the mission and meet the initially identified need and maintain support for that need. Implement the mission operations plan.	Desired system
Implementation	Phase F Closeout	To implement the systems decommissioning/disposal plan developed in Phase E and perform analyses of the returned data and any returned samples.	Product closeout

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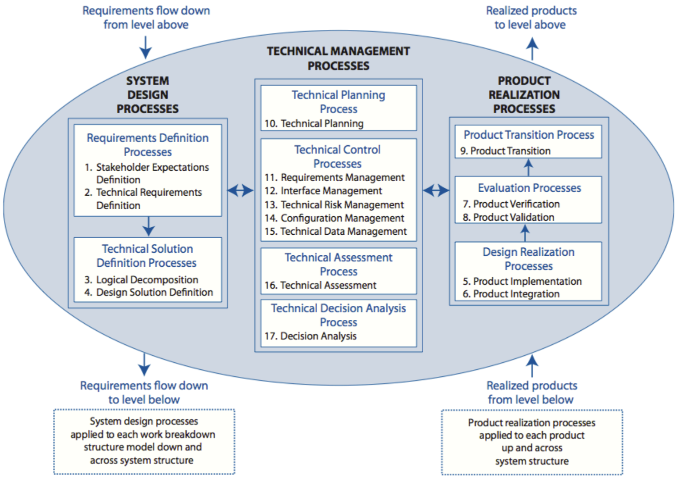
Systems Engineering Engine



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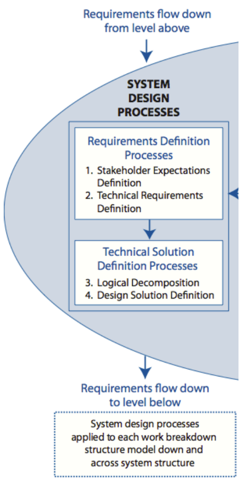
Systems Engineering Engine



- Used to define and baseline stakeholder expectations, generate and baseline technical requirements, and convert the technical requirements into a design solution that will satisfy the baseline stakeholder expectations
- These processes are applied to each product of the system structure from the top of the structure to the bottom until the lowest products in any system structure branch are defined to the point where they can be built, bought, or reused
- All other products in the system structure are realized by integration
- Designers not only develop the design solutions to the products intended to perform the operational functions of the system, but also establish requirements for the products and services that enable each operational/ mission product in the system structure

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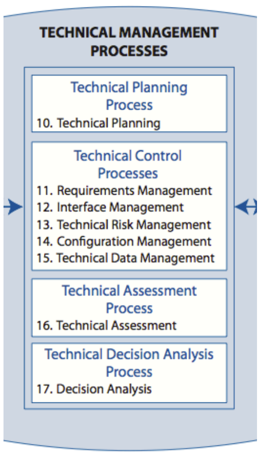
Systems Engineering Engine



- The technical management processes are used to establish and evolve technical plans for the project, to manage communication across interfaces, to assess progress against the plans and requirements for the system products or services, to control technical execution of the project through to completion, and to aid in the decision making process.

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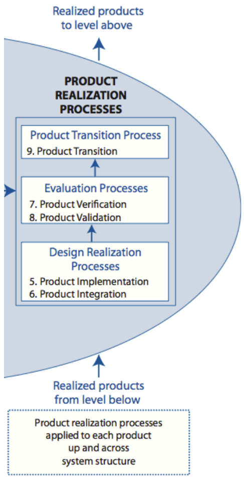
Systems Engineering Engine



- The product realization processes are applied to each operational/mission product in the system structure starting from the lowest level product and working up to higher level integrated products
- These processes are used to create the design solution for each product (e.g., by the Product Implementation or Product Integration Process) and to verify, validate, and transition up to the next hierarchical level products that satisfy their design solutions and meet stakeholder expectations as a function of the applicable life-cycle phase

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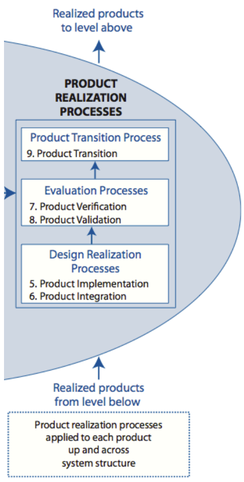
Systems Engineering Engine



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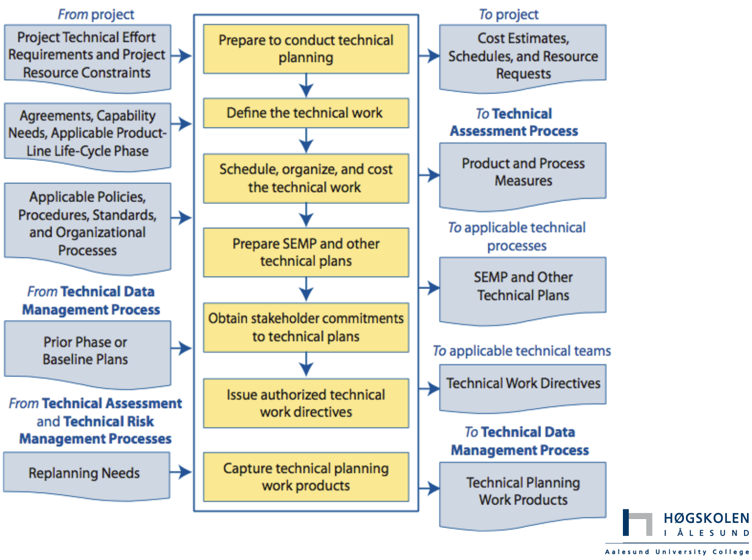
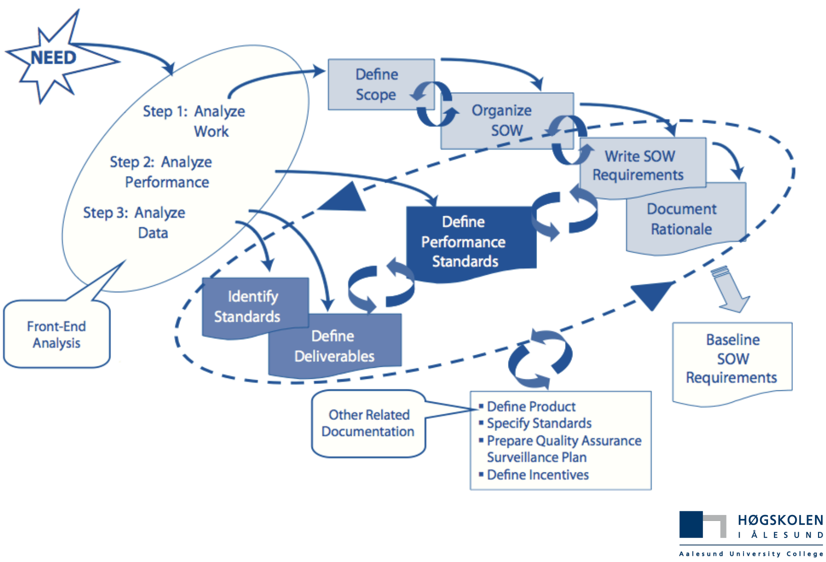
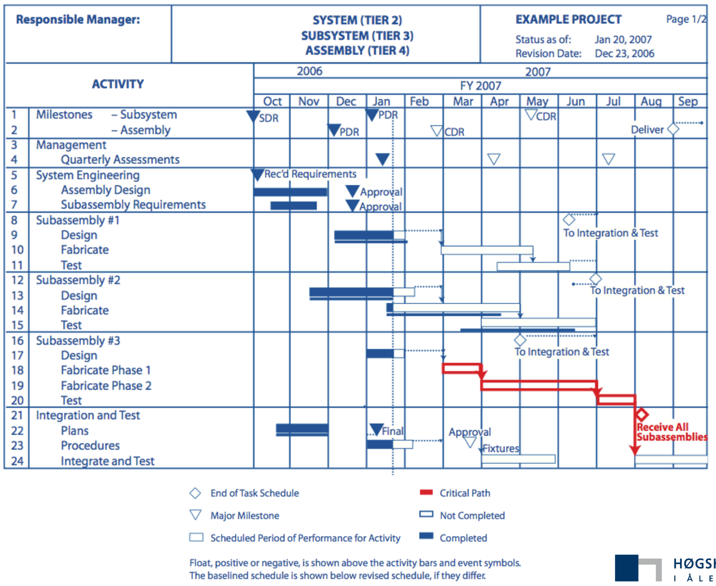
Example: Technical Planning



Example: Contract Development



Example: Gantt Chart



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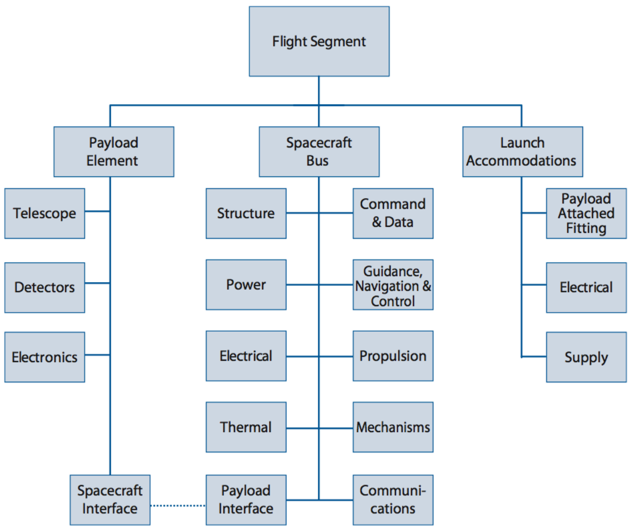
Product Breakdown Structure



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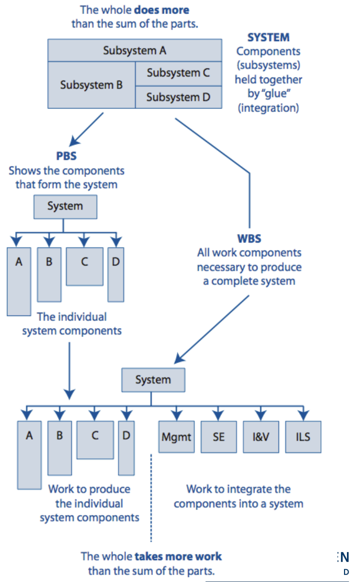
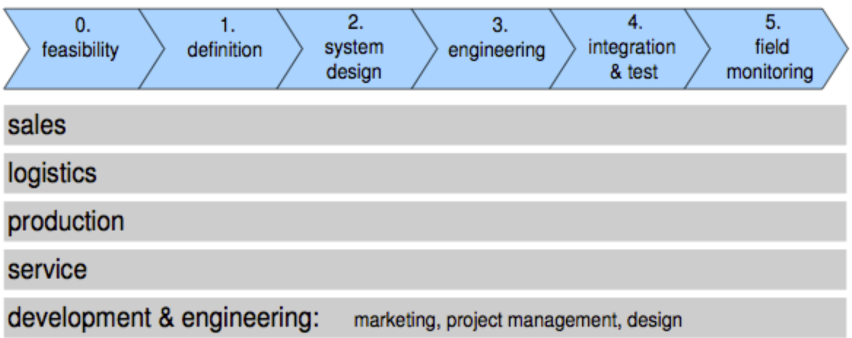
Working Breakdown Structure

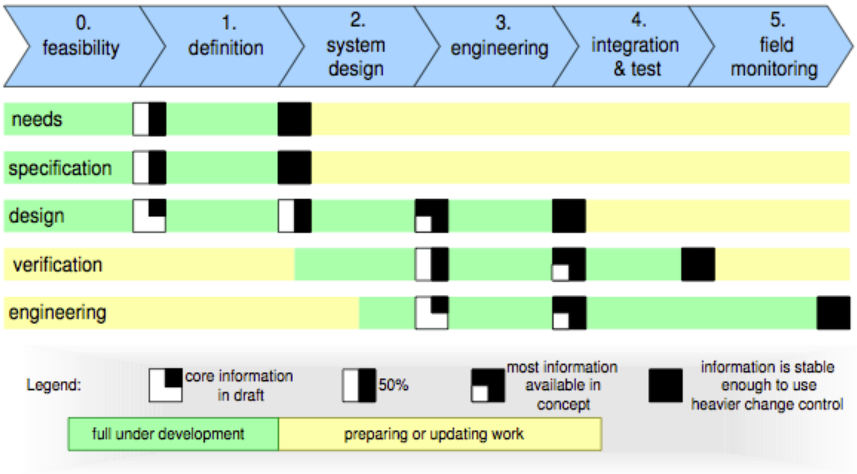
- A work breakdown structure is a hierarchical break- down of the work necessary to complete a project
- The WBS should be a product-based, hierarchical division of deliverable items and associated services
- As such, it should contain the project's Product Breakdown Structure (PBS) with the specified prime product(s) at the top and the systems, segments, subsystems, etc., at successive lower levels
- At the lowest level are products such as hardware items, software items, and information items (documents, databases, etc.) for which there is a cognizant engineer or manager.



Product Creation Process



Product Creation Process



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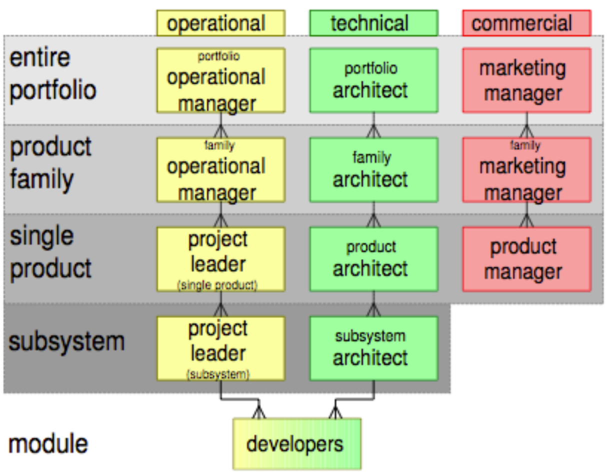
Product Creation Process



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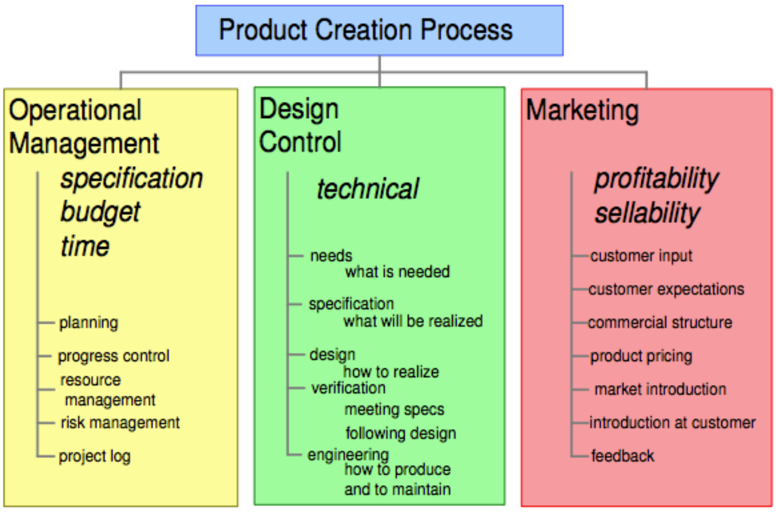
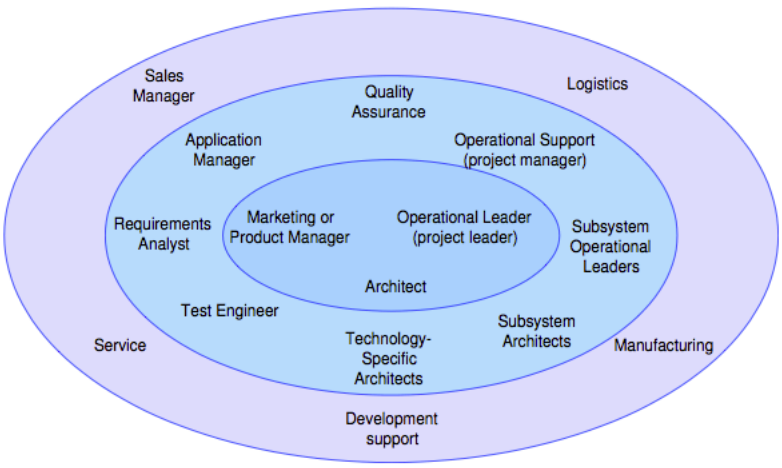
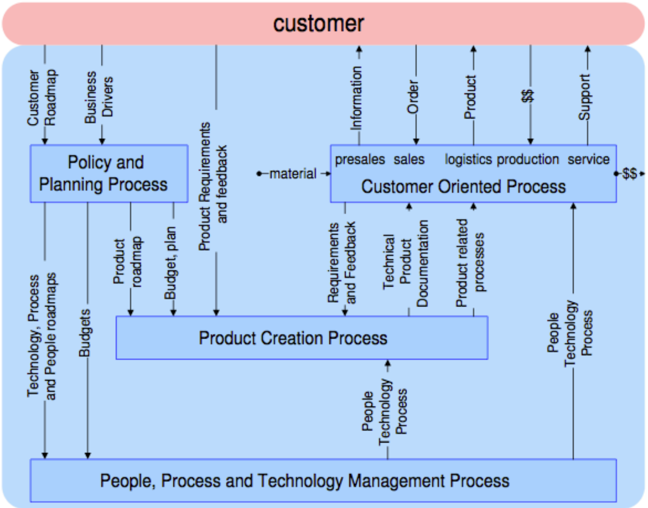
Product Creation Process



Product Creation Team



Business Process (Simplified)



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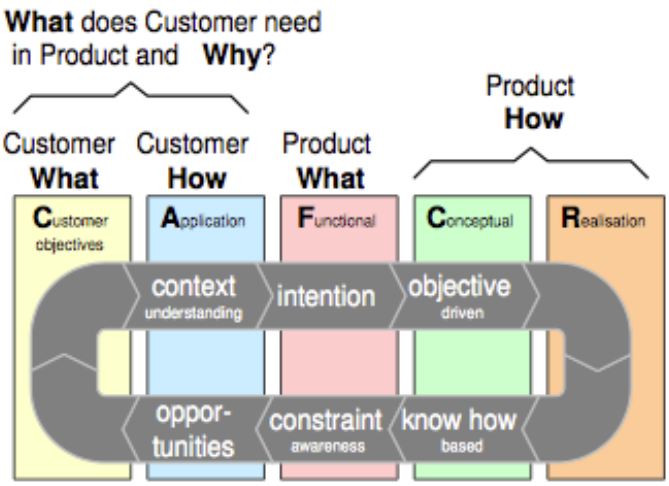
Business Process (Simplified)



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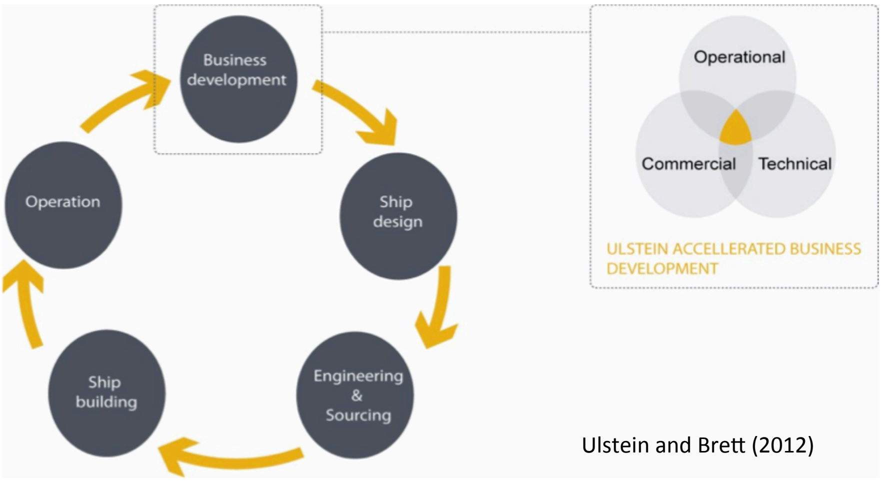
Ulstein ABD



Ulstein and Brett (2012)

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Exercise 04

1. **Based on your system designed yesterday:**
   a. Present a process for your design, with the product delivered in each of your design phases
   b. Considering the NASA SE engine, explain how the technical analysis influences the product and process during the system design process. Give an example considering a typical technical analysis from your system
   c. After the design is decided, present a simplified product breakdown structure (PBS)
   d. Based on your PBS, create a simplified working breakdown structure (WBS)
   e. How to incorporate changes in the product/process? How these changes are connected to your Lifecycle gates?

Fundamentals

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IP504914 System engineering
Best Practice Module

Week 37 – Classes Plan

Henrique Gaspar - Fall 2014
hega@hials.no - B410 (AMO)

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5 Aspects - Wednesday, Sept 10th

- **Morning:**
  - Five Aspects of Complex Systems
    - Structural
    - Behavioral
    - Contextual
    - Temporal
    - Perceptual
  - Examples
- **Exercise:**
  - Apply five aspect taxonomy to the case
  - Discuss system characteristics for each of the aspects

Literature:

1. Rhodes and Ross, "Shaping in Socio-Technical System Innovation Strategies using a Five Aspects Taxonomy", 2010
2. Rhodes and Ross, "Five Aspects of Engineering Complex Systems - Emerging Constructs and Methods", 2010
3. Gaspar, H.M. "Handling aspects of complexity in Conceptual Ship Design", 2012

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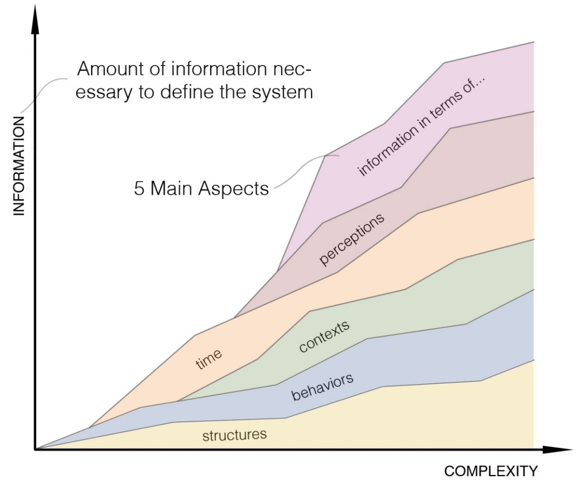
System Complexity

Handling Complexity:

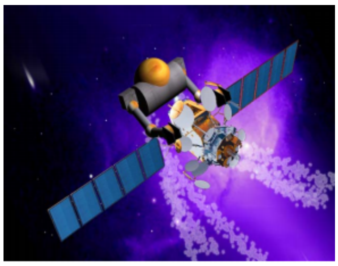


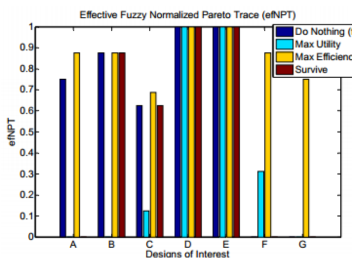
3

MIT – SEAri

Systems Engineering Advancement Research Initiative - MIT:

- Systems Engineering applied to Military and Aerospace
- Complex Systems Methods
- Methods to handle Uncertainty and Robustness
- Taxonomy and methods not yet applied in the maritime industry





4

A Taxonomic Framework

- Classification as an useful way to *organize information in order to share knowledge with others* (Rhodes & Ross, 2010)
- Embrace traditional elements, adding other important aspects - sometimes neglected during early stages – as uncertainty and robustness

Traditional

Structural: related to the form of system components and their inter-relationships

Behavioral: related to performance, operations, and reactions to stimuli

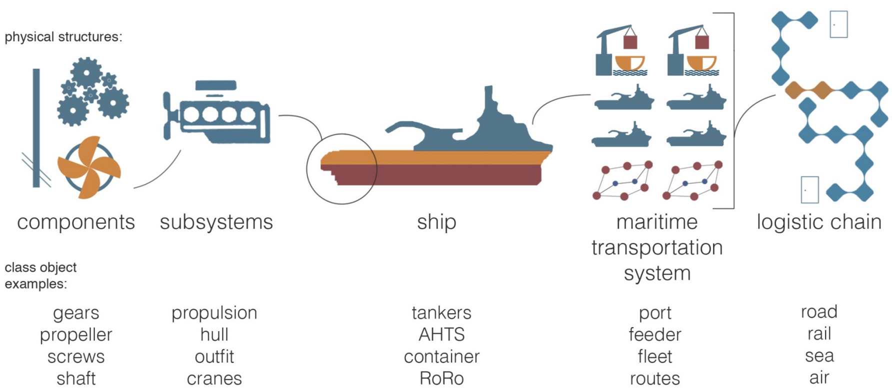
New aspects

Contextual: related to circumstances in which the system exists

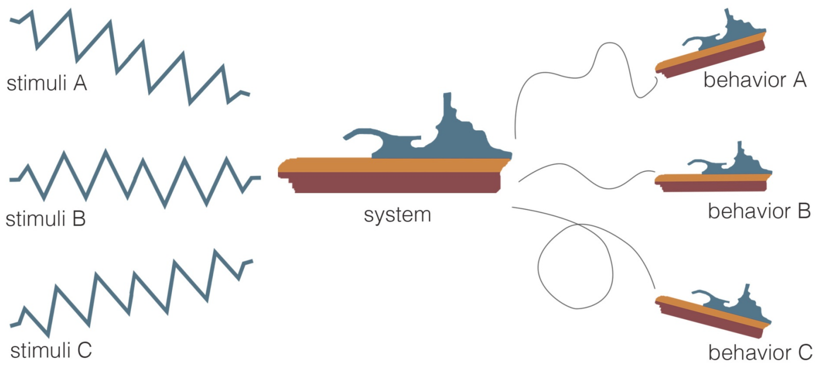
Temporal: related to dimensions and properties of systems over time

Perceptual: related to stakeholder preferences, perceptions and cognitive biases

Structural Aspect



Behavioural Aspect



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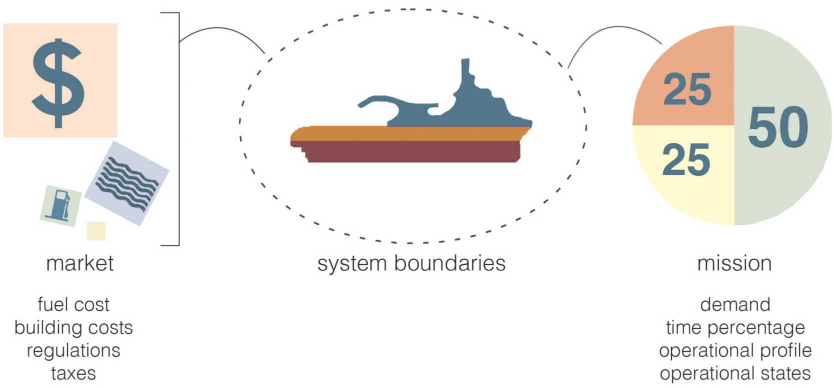
Contextual Aspect



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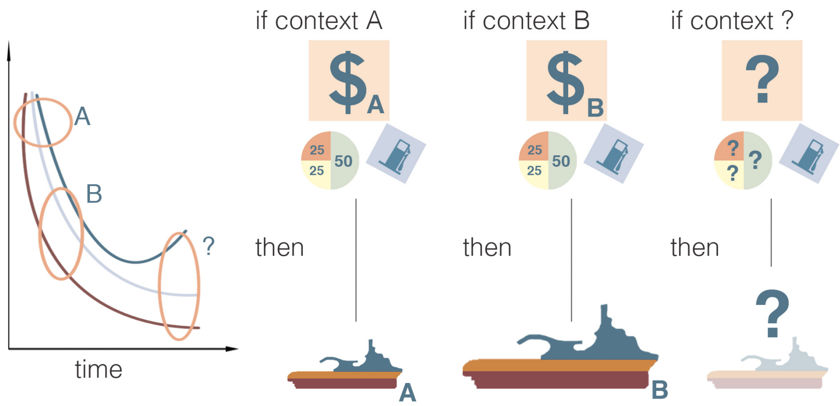
Temporal Aspect



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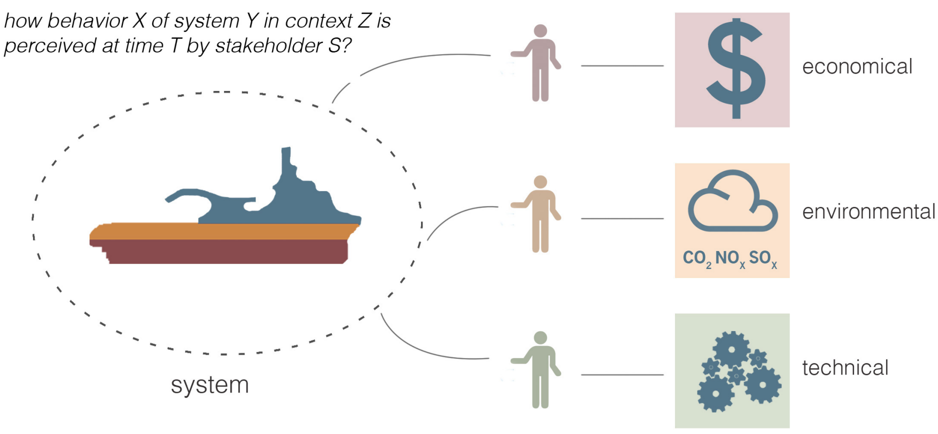
Perceptual Aspect



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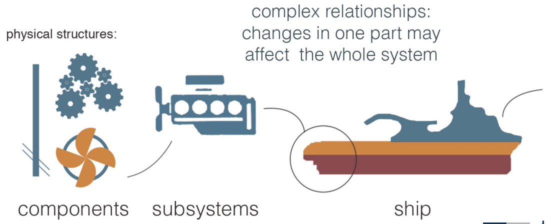
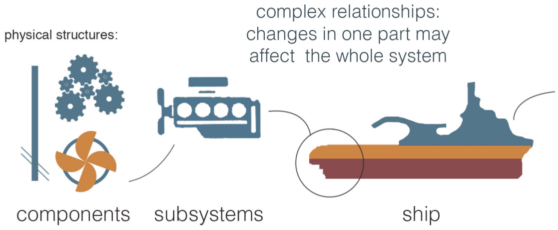
Decomposition

- Decomposability is the ability of a system to be separated into a subset of elements, making it more manageable and therefore comprehensible
- Decomposition <u>simplifies</u> the parts of a complex system, breaking into small chunks for better understanding of its components and interaction
- Normally related to the functional part



Encapsulation

- Encapsulation is a construct that facilitates the bounding of the information according to one function/process, constraining the part (subsystem) into a common ideal rationality/to-do purpose
- *"A way to accomplishing a bounding strategy"* (McClamrock)
- Encapsulation <u>simplifies</u> the connection of the subsystem with others, defining clear outputs/inputs, allowing the understanding as a whole of the main purposes/tasks/objectives of the system



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Aspect	Key Complexities	Drivers	Decomposing	Encapsulating
Structural	Interaction between components, that is, strongly coupled design	Increased number of parts; Embedded software; More focus on subsystem interaction and balck boxes	Modularization: identify near independent modules; Definition of criteria to create modules	Modularization: define inputs and outputs of each module; Definition of interface criteria to connect one module to another
Behavioral	The correct mapping between form and function, that is, to assure that a ship will perform its mission	New performance parameters to measure (for instance environmental behavior), less documented methods, with higher uncertainty	Functional breakdown, dividing the system into subsystems according to a task to be performed , then evaluating the behavior of each subsystem, for instance, via simulatio or regression analysis	Response Surface and other methods to encapsulate data from simulation
Contextual	Extension of the context entities, taking into account new elements such as sustainability and risk	Global market; Liberalization of regulations: Higher volatility in freight rate and demand	Take into account multiple operational profiles, with different context parameters in each	Standard and customized operational profiles
Temporal	Uncertainty towards context changes and future scenarios expectations	Rapid shifts of markets; Uncertainty about future in major economies; Uncertainty about new regulations	Epochs: divide the life span of the system in epoch variables; each epoch represents a snapshot of certain period of time	Eras: encapsulate changes and uncertainties into eras, that is, a time-sequenced set of epochs.
Perceptual	*What if* situations do document to different stakeholders	Larger societal concerns related to environment and social responsibility; Importance in distinguish risk prone and risk averseness	Requirements elucidation for different stakeholders	Multi-objective methods, such as AHP, Pareto.

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High Uncertainty

Aspect	Key Complexities	Drivers	Decomposing	Encapsulating
Structural	Interaction between components, that is, strongly coupled design	Increased number of parts; Embedded software; More focus on subsystem interaction and balck boxes	Modularization: identify near independent modules; Definition of criteria to create modules	Modularization: define inputs and outputs of each module; Definition of interface criteria to connect one module to another
Behavioral	The correct mapping between form and function, that is, to assure that a ship will perform its mission	New performance parameters to measure (for instance environmental behavior), less documented methods, with higher uncertainty	Functional breakdown, dividing the system into subsystems according to a task to be performed , then evaluating the behavior of each subsystem, for instance, via simulatio or regression analysis	Response Surface and other methods to encapsulate data from simulation
Contextual	Extension of the context entities, taking into account new elements such as sustainability and risk	Global market; Liberalization of regulations: Higher volatility in freight rate and demand	Take into account multiple operational profiles, with different context parameters in each	Standard and customized operational profiles
Temporal	Uncertainty towards context changes and future scenarios expectations	Rapid shifts of markets; Uncertainty about future in major economies; Uncertainty about new regulations	Epochs: divide the life span of the system in epoch variables; each epoch represents a snapshot of certain period of time	Eras: encapsulate changes and uncertainties into eras, that is, a time-sequenced set of epochs.
Perceptual	*What if* situations do document to different stakeholders	Larger societal concerns related to environment and social responsibility; Importance in distinguish risk prone and risk averseness	Requirements elucidation for different stakeholders	Multi-objective methods, such as AHP, Pareto.

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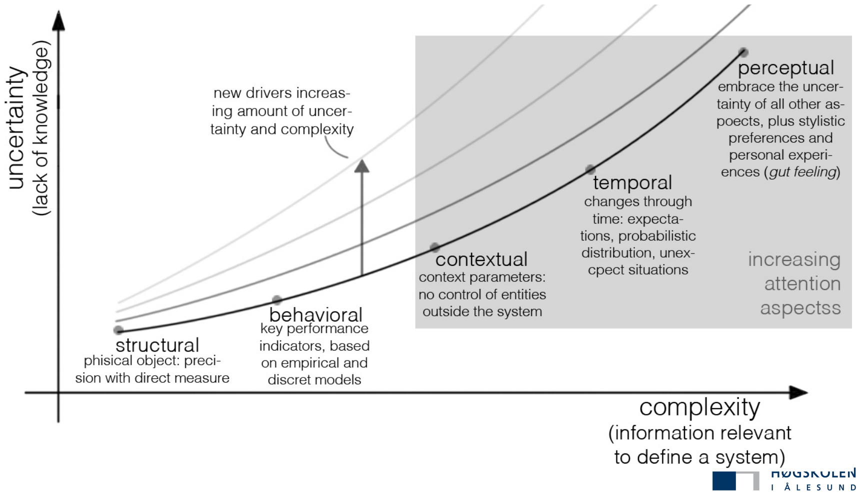
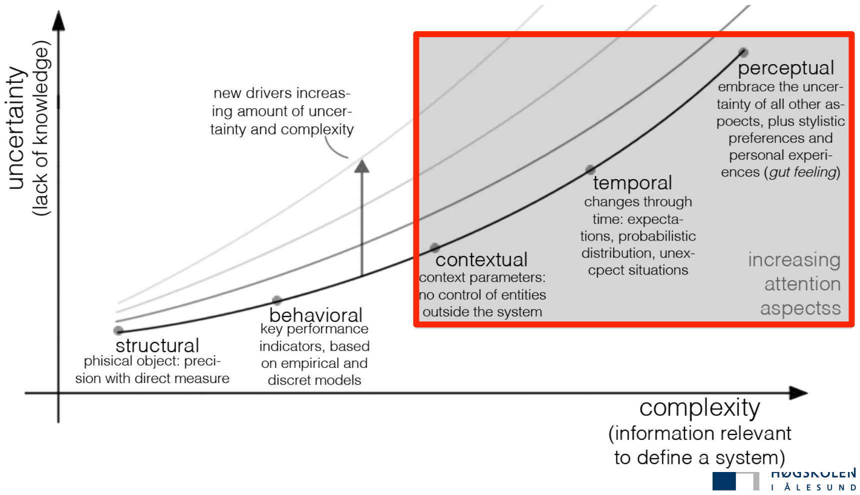
Uncertainty

Each of the complexity aspects has a certain level of uncertainty



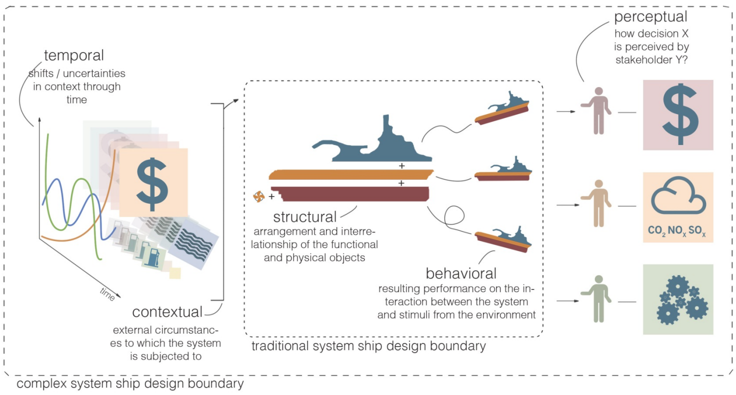
Uncertainty

Each of the complexity aspects has a certain level of uncertainty



NTNU
Norwegian University of Science and Technology

Handling Complexity in Maritime Design



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Exercise 05

1. **Based on your system designed yesterday:**
   a. Apply the taxonomy to your system. What are the
      - Structural aspects
      - Behavioral Aspects
      - Contextual Aspects
      - Temporal Aspects
      - Perceptual Aspects

   b. How do you deal with uncertainty in each of the aspects? Sketch a brief "what if"

Fundamentals

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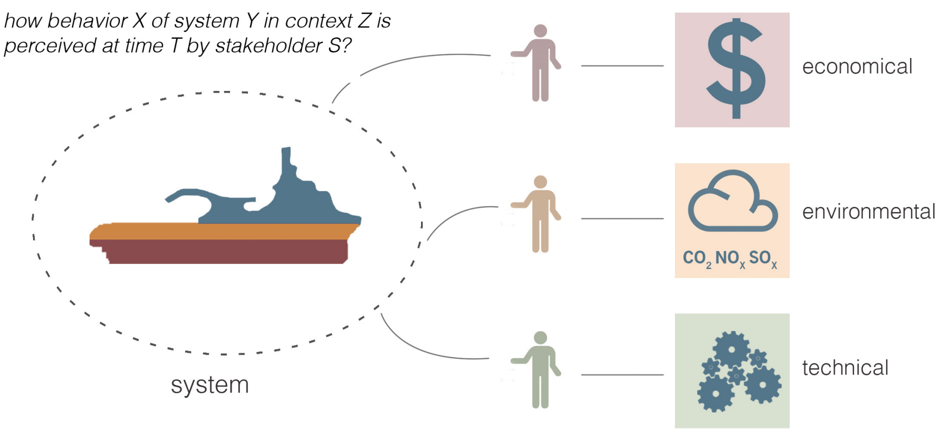
Decision Making
Wednesday, Sept 10th

- **Afternoon:**
  - Perceptual Aspect
  - Stakeholders
  - How "good" is perceived?
  - Decision Making
  - Measures of Effectiveness
  - Decision Matrix
  - Decision Tree – what is the "value" of a decision?
  - Examples
- **Exercise:**
  - Develop a simple decision making tool for your case (AHP or Matrix)
  - Decision Tree for Key investment
  - Perceptual aspect discussion

Literature:

1. Rhodes and Ross, "Five Aspects of Engineering Complex Systems - Emerging Constructs and Methods", 2010
2. Haskins, C., "Systems Engineering Handbook – A guide for Lifecycle Processes and Activities", 2006
3. March, J. "A Primer on Decision Making: How Decisions Happen", 1994
4. Ulstein, T., and Brett, P. O. "Critical systems thinking in ship design approaches." International Maritime Design Conference - Glasgow (2012).
5. Erikstad, S. O. "Design Methods – NTNU Course", 2009
6. Dahl, J. "Systems Engineering Course at NTNU", 2009
7. Oliver, D. et al. Engineering Complex Systems with Models and Objects", 1996

Perceptual Aspect



Measures of Effectiveness

A way to measure "success"

Some qualities of MOE:

- They represent the viewpoint of stakeholders; those who have a right to impose requirements on a solution
- They assist in making the right choice by indication “how well” a solution meets the stakeholders need
- MOE should be able to be quantified in some manner

Purpose: How is it possible to recognize success?

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Measures of Effectiveness (MOE)

- MOEs are standards against which the capability of a solution to meet the needs of a problem may be judged
- MOEs are independent of any solution and specify neither performance nor criteria
- MOEs are the small subset of requirements that are so important that the system will fail if they are not met and will be a huge success if they are met

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Measures of Effectiveness (MOE)

Ex:

- 50.000 of electrical cars by 2018 (Parliament - Norway)
- Identification of fish in the River Thames as a MOE for cleaning the river
- The F-117 stealth fighter that did not suffer a hit and that kills bats in the hangars

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System Stakeholders

A stakeholder is any entity (individual or organization) with a legitimate interest in the system. Typical stakeholders include users, operators, organization decision-makers, parties to the agreement, regulatory bodies, developing agencies, support organizations, and society-at-large. When direct contact is not possible, systems engineers find agents, such as marketing or non- governmental organizations, to represent the concerns of a class of stakeholders, such as consumers or future generations

24

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System Stakeholders

- All systems have a group of stakeholders having interests in the system.
- The stakeholders may be classified or grouped as follows:
  - The customers, those who pay for and own the system
  - The users, those who use the system, sometimes identical to the customers, but usually not
  - The developers, those who design, develop, manufacture, and implement the system, ”bringing the system into being”
  - Government and public authorities, those who set the rules for design and operation of the system
  - The so-called ”Third Party”, those who are inadvertently affected by the system, its existence and operation

25

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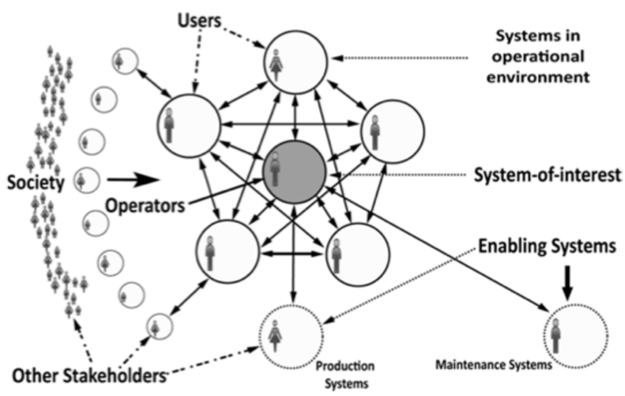
System Stakeholders

- Stakeholders have requirements to the system:
  - Structural
  - Behavioral
  - Contextual
  - Temporal
  - Perceptual



26

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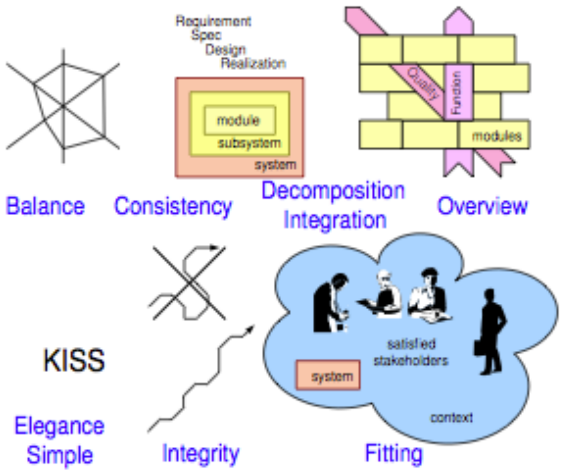
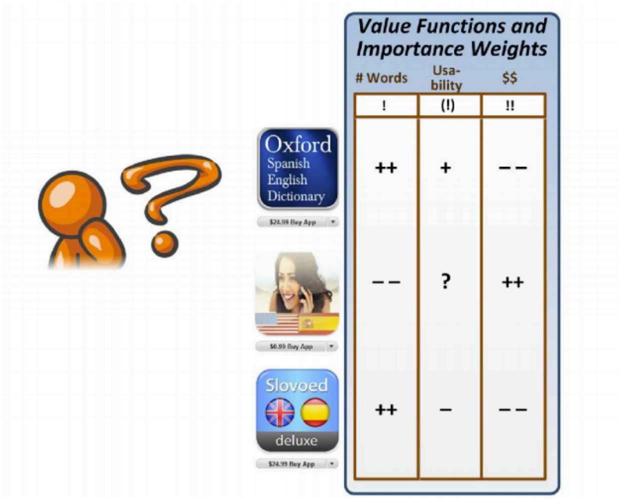
Idea of Rational Choice

- **Alternatives:** What actions are possible?
- **Expectations:** What future consequences? How likely is each consequence?
- **Preferences:** How valuable are the consequences?
- **Decision rule:** How is a choice to be made among the alternatives?

Perception Responsibilities



Classical View



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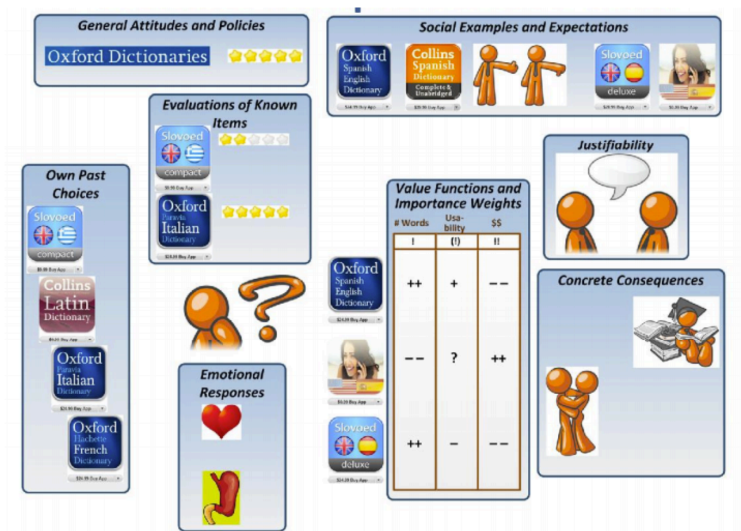
More Comprehensive View



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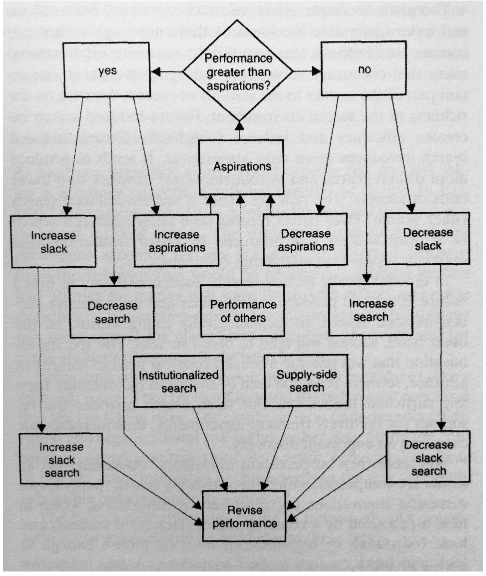
Model of Satisficing Search



J. March

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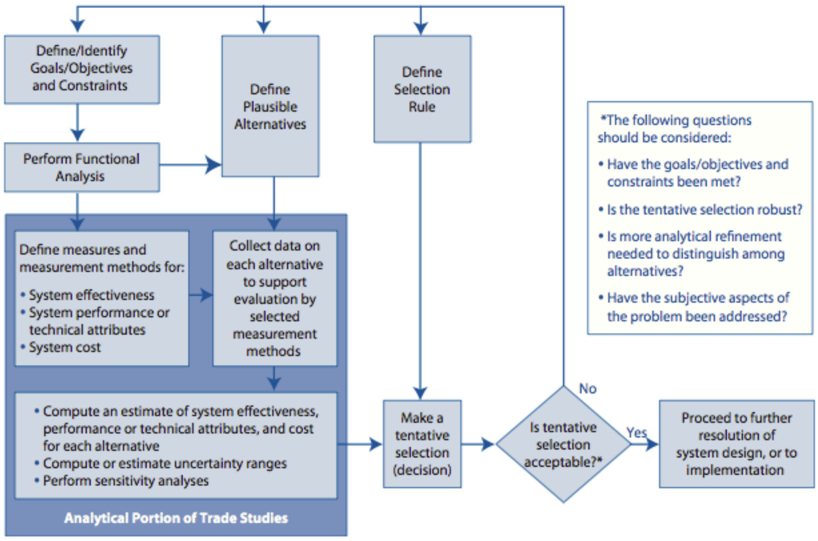
NASA Case



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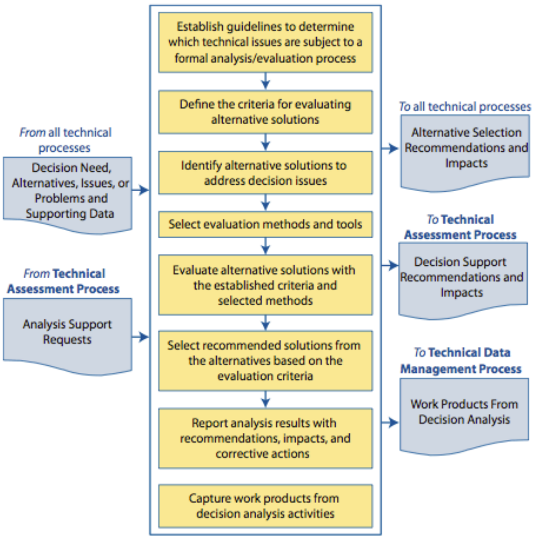
Decision Analysis Process (NASA)



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Decision Report

#	Section	Section Description
1	Executive Summary	Provide a short half-page executive summary of the report: • Recommendation (short summary—1 sentence) • Problem/issue requiring a decision (short summary—1 sentence)
2	Problem/Issue Description	Describe the problem/issue that requires a decision. Provide background, history, the decisionmaker(s) (e.g., board, panel, forum, council), and decision recommendation team, etc.
3	Decision Matrix Setup Rationale	Provide the rationale for setting up the decision matrix: • Criteria selected • Options selected • Weights selected • Evaluation methods selected Provide a copy of the setup decision matrix.
4	Decision Matrix Scoring Rationale	Provide the rationale for the scoring of the decision matrix. Provide the results of populating the scores of the matrix using the evaluation methods selected.
5	Final Decision Matrix	Cut and paste the final spreadsheet into the document. Also include any important snapshots of the decision matrix.
6	Risk/Benefits	For the final options being considered, document the risks and benefits of each option.
7	Recommendation and/or Final Decision	Describe the recommendation that is being made to the decisionmaker(s) and the rationale for why the option was selected. Can also document the final decision in this section.
8	Dissent	If applicable, document any dissent with the recommendation. Document how dissent was addressed (e.g., decision matrix, risk, etc.).
9	References	Provide any references.
A	Appendices	Provide the results of the literature search, including lessons learned, previous related decisions, and previous related dissent. Also document any detailed data analysis and risk analysis used for the decision. Can also document any decision metrics.

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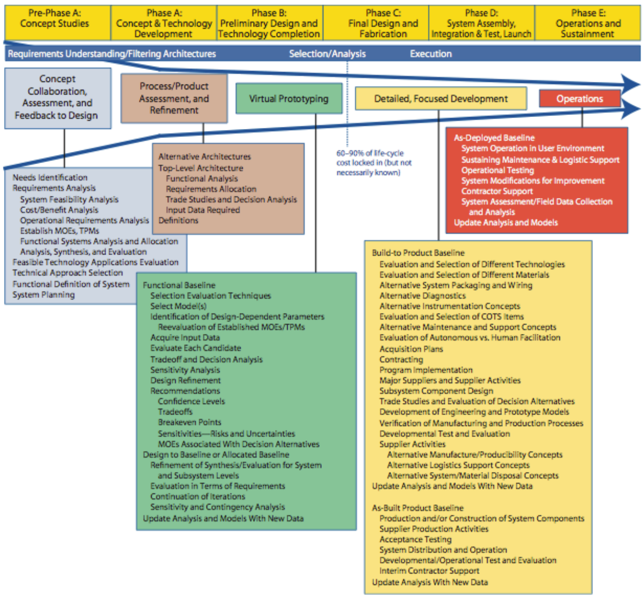
Analysis through Lifecycle



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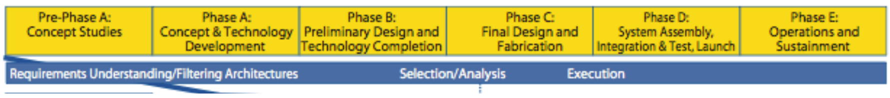
Analysis through Lifecycle



Acceptable: Proceed with the next stage of the project;

Or *Acceptable with reservations*: Proceed and respond to action items;

Unacceptable: Do not proceed; continue this stage and repeat the review when ready;

Unacceptable: Return to a preceding stage;

Unacceptable: Put a hold on project activity;

Unsalvageable: Terminate the project.

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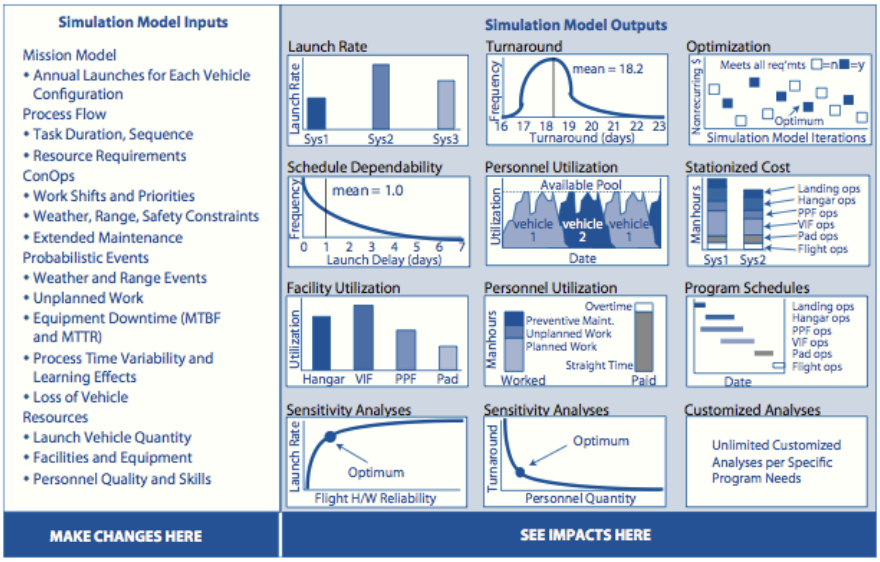
Simulation Dashboard



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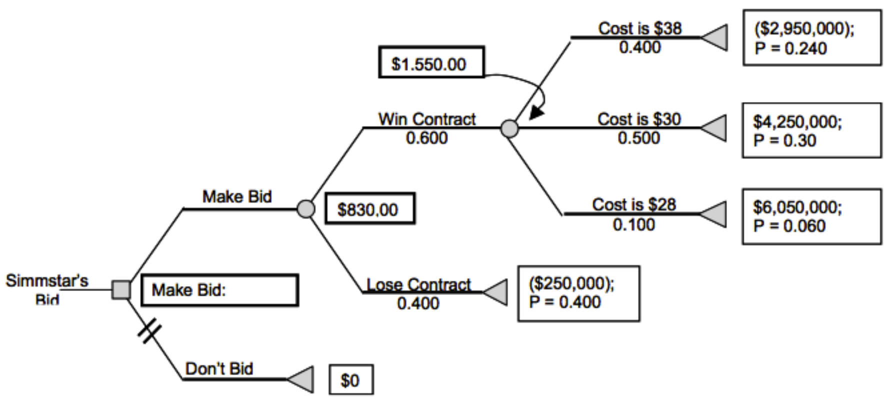
Decision Tree



Contract Win Expected Value = 10% * $6.05 M + 50% * $4.25 M – 40% * $2.95M or $1.55M

The expected value of making the bid is 60% * $1.55 – 40% * 0.25 or $0.83 M

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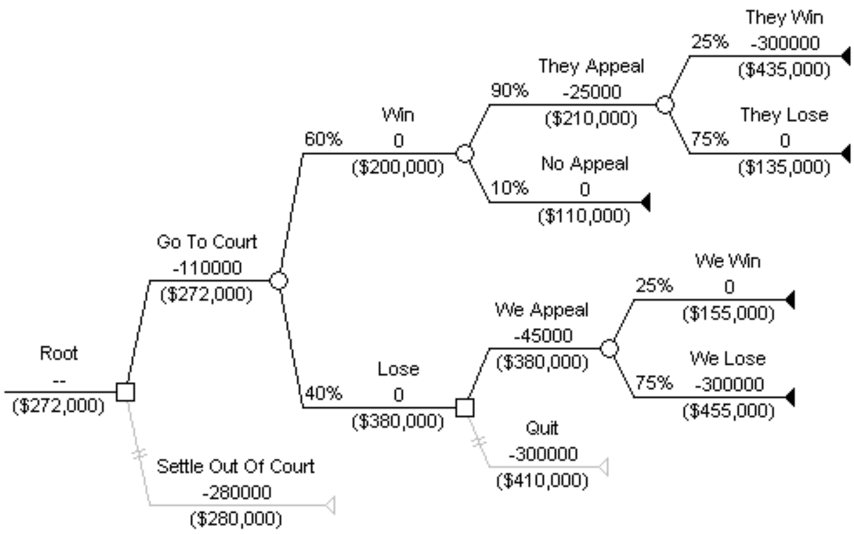
Decision Tree



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Decision Matrix

Example of Comparison

	Criterion 1	**Criterion 2**	**...**	**Criterion *N***
Alternative 1	x_{11}	x_{12}	...	x_{1N}
Alternative 2	x_{21}	x_{22}	...	x_{2N}
...	...	...	X_{ij} = Good	...
Alternative *M*	x_{M1}	x_{M2}	...	x_{MN}
Sum				
Rank				
Status		No		No

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Decision Matrix

	%Value	Car 1	Car 2	Car 3
Price	30%	105	90	105
Operating Cost	10%	35	20	45
Styling	20%	50	90	60
Comfort	20%	80	50	70
Handling	15%	45	60	45
Safety	5%	17.5	12.5	20
Totals		332.5	322.5	345

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Decision Matrix

Decision Matrix
Example for Battery

CRITERIA	Mandatory (Y=1/N=0)?	Weight	SCALE (ENTER SCORES)	Extend Old Battery Life	Buy New Batteries	Collect Experient Data With Alternative Experiment	Cancelled Experiment
Mission Success (Get Experiment Data)	1	30	3 = Most Supportive 1 = Least Supportive	2	3	3	0
Cost per Option	0	10	3 = Least Expensive 1 = Most Expensive	1	2	3	1
Risk (Overall Option Risk)	0	15	3 = Least Risk 1 = Most Risk	2	1	2	3
Schedule	0	10	3 = Shortest Schedule 1 = Longest Schedule	3	2	1	3
Safety	1	15	3 = Most Safe 1 = Least Safe	2	1	2	3
Uninterrupted Data Collection	0	20	3 = Most Supportive 1 = Least Supportive	3	1	2	1
WEIGHTED TOTALS in %		100%	3	73%	60%	77%	0%
			SCALE 1-3				

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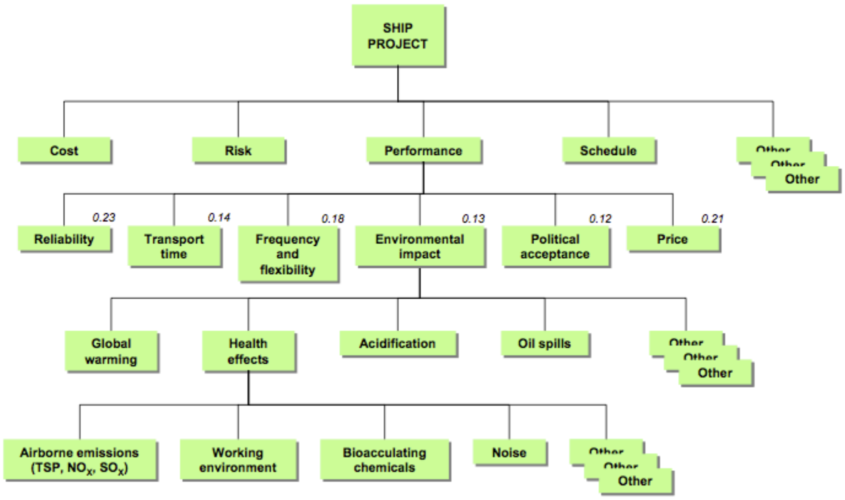
Detailed Decision



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Future Study - AHP

Choose the best car for the Jones family									
	Cost				Safety	Style	Capacity		
Model	Purchase Price	Fuel Costs	Maint. Costs	Resale Value			Cargo Capacity	Pass. Capacity	Total
Accord Sedan	0.060	0.024	0.018	0.018	0.051	0.015	0.003	0.025	0.213
Accord Hybrid	0.007	0.027	0.016	0.008	0.051	0.015	0.003	0.025	0.150
Pilot SUV	0.007	0.017	0.004	0.004	0.020	0.002	0.006	0.049	0.109
CR-V SUV	0.060	0.020	0.005	0.034	0.009	0.007	0.006	0.025	0.165
Element SUV	0.089	0.019	0.004	0.009	0.006	0.001	0.006	0.008	0.143
Odyssey Minivan	0.025	0.020	0.003	0.009	0.100	0.003	0.011	0.049	0.220
TOTALS	*0.246*	*0.127*	*0.050*	*0.081*			*0.036*	*0.181*	*1.000*
	0.504				0.237	0.042	0.217		*1.000*
	1.000								

Analytical Hierarchy Process

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Exercise 06

1. **Based on your system designed yesterday:**
   a. Present a simple decision tree, comparing the investment in your system versus investing in Bank funds (2.5% yearly)
   b. Describe a list of the main stakeholders, and how they perceive value in your system.
   c. Create a unique measure of effectiveness for your system
   d. Create a simple Decision Matrix for comparing designs
   e. Based on c) and d), explain how each of the stakeholders in b) perceive value in your system. Incorporate topics from the perceptual aspect.

IP504914 System engineering
Best Practice Module

Week 37 – Classes Plan

Henrique Gaspar - Fall 2014
hega@hials.no - B410 (AMO)

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Combining Methods Thursday, Sept 11th

- **Morning:**
  - Near-decomposable systems
  - Combining Methods
  - SE techniques x non-SE Techniques
  - RSC and Epoch-Era Analysis
  - Case Studies
- **10-16 – Project Proposal:**
  - Sketch a proposal
  - Elevator pitch
  - 2 page presentation (14:00):
    - Introduction
    - Scope
    - Objective
    - Milestones
    - Deliveries
  - What is your focus (es)?

Literature:

1. Simon, H. "Sciences of Artificial", 1996
2. Gaspar, H.M. "Handling aspects of complexity in Conceptual Ship Design", 2012
3. Gaspar, H. et al., "Handling temporal complexity in the design of non-transport ships using epoch-era analysis", 2011
4. Ross, A.M.,et al. "Responsive Systems Comparison Method: Dynamic Insights into Designing a Satellite Radar System,", 2009
5. Muller, G. "System Architecting", 2010

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Combining Methods Thursday, Sept 11th

- **To see as example:**
  - Near-decomposable systems – Simon 1962
  - Combining Methods – Merging theories (Gaspar 2012)
  - SE techniques x non-SE Techniques (SE x Analysis x Management)
  - RSC (SEAri) and Epoch-Era Analysis (Ross et al.)
  - Case Studies – Arctic LNG

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Project Work

- Groups of **2 or 3**
- Pick a theme/system/process that you would like to tackle via **Systems Engineering**
  - What is the problem/question/issue?
  - Why is this important?
  - What have others done (i.e. what is the current situation)
  - What must be done (i.e. what you plan to change/ understand/solve in the future)

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Project Work

- Sketch a 2 page proposal containing:
  - **Introduction**: Explain briefly what is the system, important aspects, your aspects among others, what is the current situation, how it can be improved.

Example:

"Anchor handling tug supply vessels (AHTS) are produced to support the development, maintenance and repair of oil and gas offshore fields, in a wide range of operations. There are different types of vessels, some of them with standard equipment, others tailor-made for a specific mission. A more operational versatile and cost-competitive vessel is the current challenge of the industry."

Project Work

- **Object**: To which extent you will be considering your problem/issue/question? What are the parts that you will consider?

Example:

"The scope of the project is the conceptual phase of design and preliminary assessment of operability based on the main capabilities installed on board given a certain group of missions."

Project Work

– **Objective**: What your project aim to do? What are the goal(s)?

Example:

"The objective of the project is to present an entire but simplified iteration of the operational value (Operability) assessment in AHTS, linking the mission parameters until a unique operational measure during the early stages of design."

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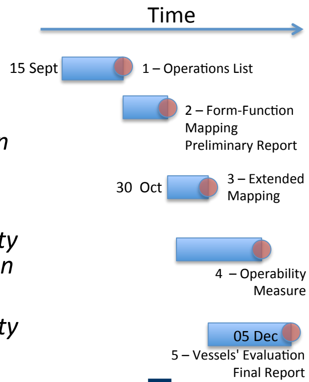
Project Work

– **Milestones**: What are the main tasks? How you will progress your work? How it will be development?

Example:

Tasks

1. *Identification of main AHTS operations*
2. *Mapping between installed capabilities (form) and operational functionality (function) for one vessel in one operation*
3. *Extension of the Mapping to diverse capabilities and diverse operation*
4. *Evaluate an operation based on the ability of a vessel perform it given equipment on board, defining an Operability measure*
5. *Evaluate vessels based on their operability value*



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Project Work

– **Deliveries**: What will be delivered?

Example:

Report with introduction, scope, objectives (goals), methodology, analysis, results and discussion of the main tasks:

1. *Identification of main AHTS operations*
2. *Mapping between installed capabilities (form) and operational functionality (function) for one vessel in one operation*
3. *Extension of the Mapping to diverse capabilities and diverse operation*
4. *Evaluate an operation based on the ability of a vessel perform it given equipment on board, defining an Operability measure*
5. *Evaluate vessels based on their operability value*

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Exercise 07

Group exercise (2 or 3 – SAME group as project)

1. Sketch a 1-2 page project proposal about containing:
   a. Introduction
   b. Scope
   c. Objective
   d. Milestones
   e. Deliveries

2. 14:00 - Present a "elevator pitch" of you proposal to be discussed in class (no need of power-point, just paper)

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