ENES 489P Hands-On Systems Engineering Projects

Introduction to Systems Engineering

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Administrative Issues

Class Web Page

See:

http://www.isr.umd.edu/∼austin/ense489p.html

Class Syllabus

Outlined on the class web page ...

Assessment

Project presentation and report will count for 60% of the final grade.

Lecture 1: Getting Started

Topics:

1. Career opportunities in Systems Engineering.
2. Our definition of Systems Engineering.
3. Case Study: Systems Engineering for Modern Buildings.
4. Systems Engineering in Mainstream US Industry.
5. End-to-end Lifecycle Development.
6. Models of Systems Engineering Development (e.g., Waterfall, Spiral).
7. Economics of development.

Lecture 1: Getting Started

At the end of this lecture you should be able to answer:

1. What is systems engineering?
2. What kinds of problems does the discipline try to solve?
3. Why is systems engineering important?
4. What does a typical systems engineering lifecycle look like?
5. What are the economic consequences of failing to do proper systems engineering?
6. Are there any jobs in Systems Engineering?

Career Opportunities in Systems Engineering

SYSTEMS ENGINEER: "BEST JOB IN AMERICA"

Money Magazine

Best Jobs in America by Donna Rosato with Beth Braverman and Alexis Jeffries. Oct. 9, 2009
Source: MoneyOnCNNMoney.com

"Money and PayScale.com, a leading online provider of employee-compensation data, surveyed 35,000 people online about what makes a great job, they rated intellectual challenge, a passion for the work, and flexibility just as highly as security.

1. **Systems Engineer**

Median salary (experienced): $ 87,100
Top pay: $130,000
Job growth (10-year forecast): 45%
Sector: Information Technology

What they do: They're the "big think" managers on large, complex projects, from major transportation networks to military defense programs. They figure out the technical specifications required and coordinate the efforts of lower-level engineers working on specific aspects of the project.

Why it's great: Demand is soaring for systems engineers, as what was once a niche job in the aerospace and defense industries becomes commonplace among a diverse and expanding universe of employers, from medical device makers to corporations like Xerox and BMW. Pay can easily hit six figures for top performers, and there's ample opportunity for advancement. But many systems engineers say they most enjoy the creative aspects of the job and seeing projects come to life. "The transit system I work on really makes a tangible difference to people," says Anne O'Neil, chief systems engineer for the New York City Transit Authority.

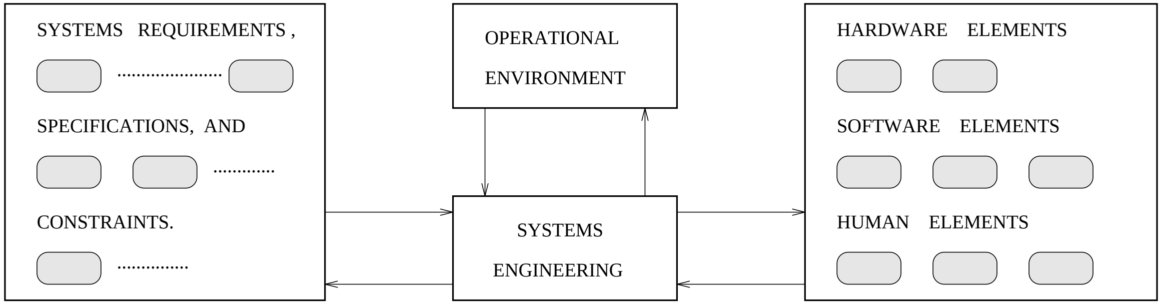
Drawbacks: Long hours are common; project deadlines can be fierce.

Pre-reqs: An undergrad engineering degree; some jobs might also require certification as a certified systems engineering professional (CSEP)."

http://finance.yahoo.com/career-work/article/107926/best-jobs-in-america.html

Our Definition of Systems Engineering

Systems engineering is a discipline that lies at the cross-roads of engineering and business concerns.



Specific goals are to provide:

1. A balanced and disciplined approach to the **total integration** of the system building blocks with the surrounding environment.
2. A methodology for systems development that focussed on **objectives**, **measurement**, and **accomplishment**.
3. A systematic means to acquire information, and sort out and identify areas for **trade-offs** in cost, performance, quality etc....

Practicing Systems Engineers

Typical concerns on the design side:

1. What is the required functionality?
2. How well should the system perform?
3. What about cost/econmics?
4. How will functionality/performance be verified and validated?

Typical concerns on the management side:

1. What processes need to be in place to manage the development?
2. What kind of support for requirements management will be needed?

Learning how to deal with these concerns in a systematic way is a challenging proposition driven, in part, by a constant desire to improve system performance and extend system functionality.

Understanding System Complexity

To understand a system, you really need to understand:

1. The ways in which it will be used,
2. The environment in which it will operate, and
3. The knowledge, technologies, and methods that go into making it.

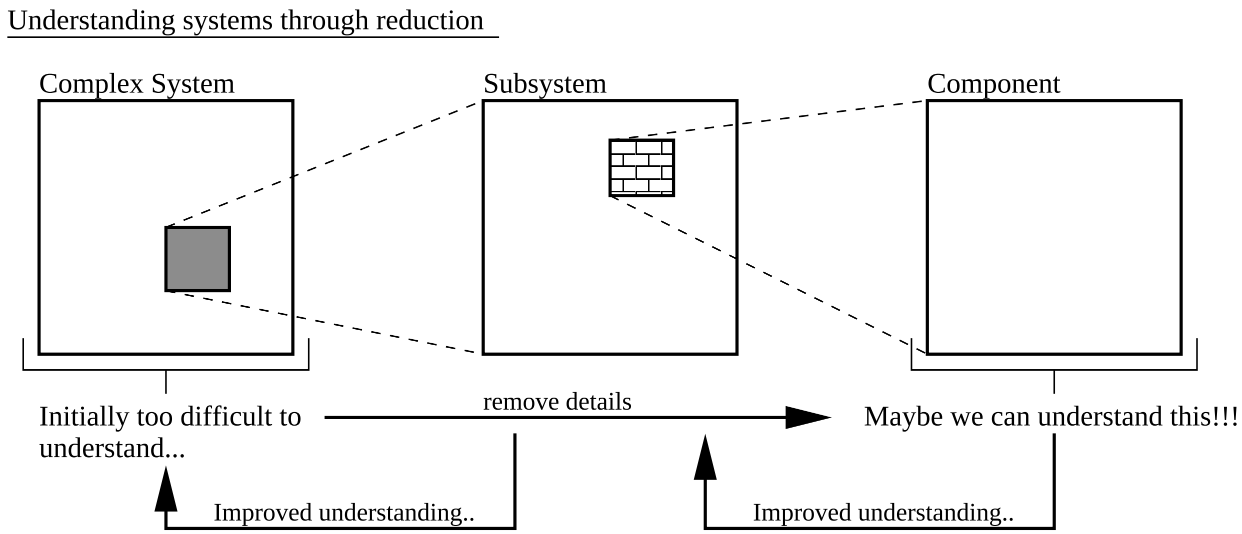
For a wide range of engineering applications this problem is quite tractable.

However as systems become more complex, we need to be strategic in the way we approach design, i.e., points to the importance of:

1. System Decomposition (to simplify design).
2. Abstractions (to simplify decision making in design).
3. Formal Analysis (our understanding of system behavior needs to be right).

Understanding System Complexity

Strategy: Put original problem aside and focus on understanding the collection of subsystems that make up the orginal system.

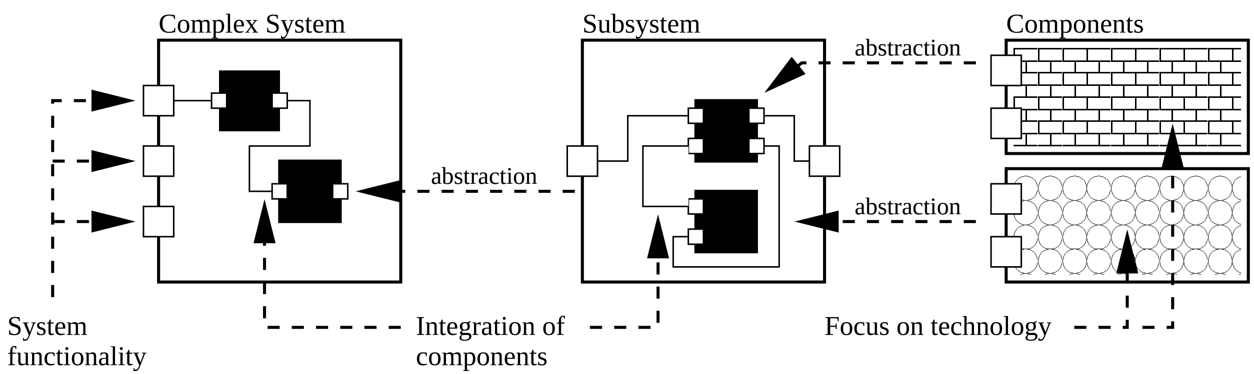


Common questions include:

1. What are the subsytems and how are they connected internally?
2. How does the system interact with the surrounding environment?

System Assembly via Integration of Abstractions

System assembly through integration of abstractions



Observations

Increasing importance of technology →

← Increasing range of functionality

← Increasing opportunity for reuse of lower level entities

Engineering Concerns

← Increasingly heterogeneous Increasingly homogeneous →

← Increasing use of abstraction

← Increasing need for formal analysis

Case Study: SE for Modern Buildings

Modern buildings are:

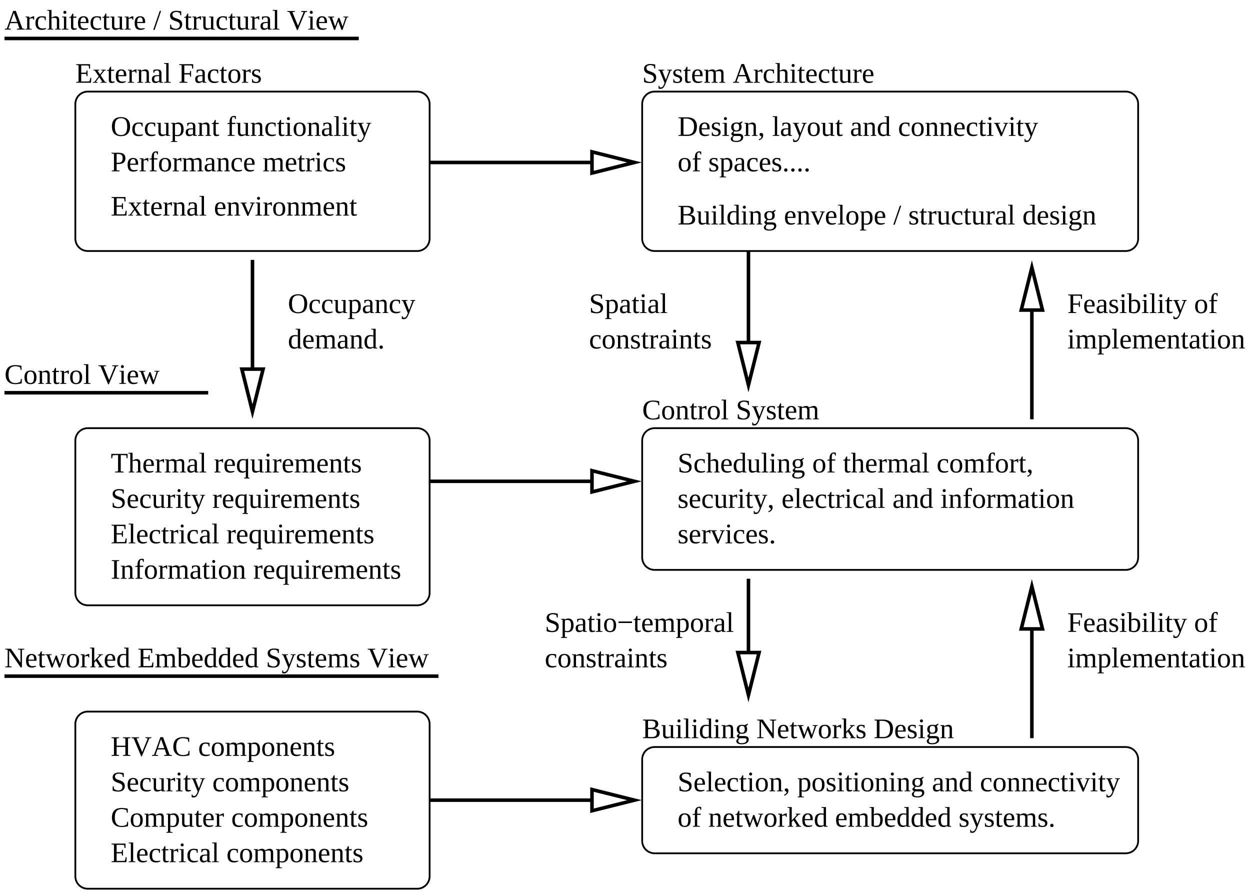
> **... advanced, self-contained and tightly controlled environments designed to provide services (e.g., transportation, artificial lighting, ..etc.).**

The design of modern buildings is complicated by:

1. Necessity of performance-based design and real-time management.
2. Many stakeholders (owners, inhabitants), some with competing needs.
3. Large size (e.g., 30,000 occupants; thousands of points of sensing and controls for air quality and fire protection.)
4. Intertwined network structures for the arrangement of spaces, fixed circulatory systems (power, hvac, plumbing), dynamic circulatory systems (flows of energy through rooms; flows of material).

Case Study: SE for Modern Buildings

Framework for interaction of architectural, structural, control, and networked embedded system design activities.



Case Study: SE for Modern Buildings

System Level	Subsystem Level	Component Level
Architectural Concerns		
Form and functionality. Services, access, comfort.	Floor level spaces, positioning of spaces, connectivity among spaces.	Walls and spaces, portals, doorways, windows ...
Structural Concerns		
Structural assemblies, overall system stability	Frame, floor, and wall systems. Forces, deflections.	Beam and column elements, beam/column joints, material behavior.
Electro-mechanical Concerns		
Access, comfort, safety	HVAC, lighting, fire protection	Heat exchangers, pipes, elevators, escalators, sprinklers

SE in Mainstream US Industry

Traditional engineering and systems engineering serve complimentary roles:

- **Traditional Engineering**.

  Focus on generation of knowledge needed to ceate new technologies and new things.

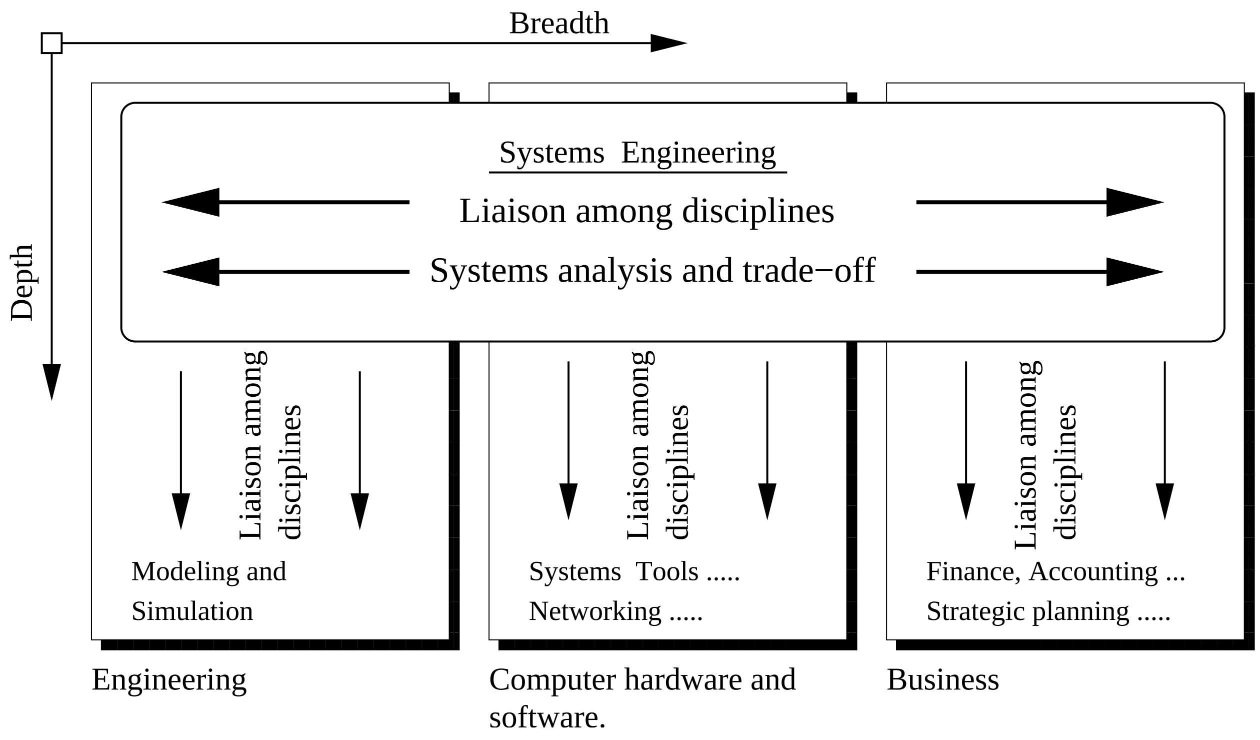
- **Systems Engineering**.

  Focus on understanding how existing technologies and things can be integrated together in new ways (...to create new kinds of systems).

So here's the bottom line:

... systems engineers need traditional engineers, and vice versa.

SE at the Organizational Level

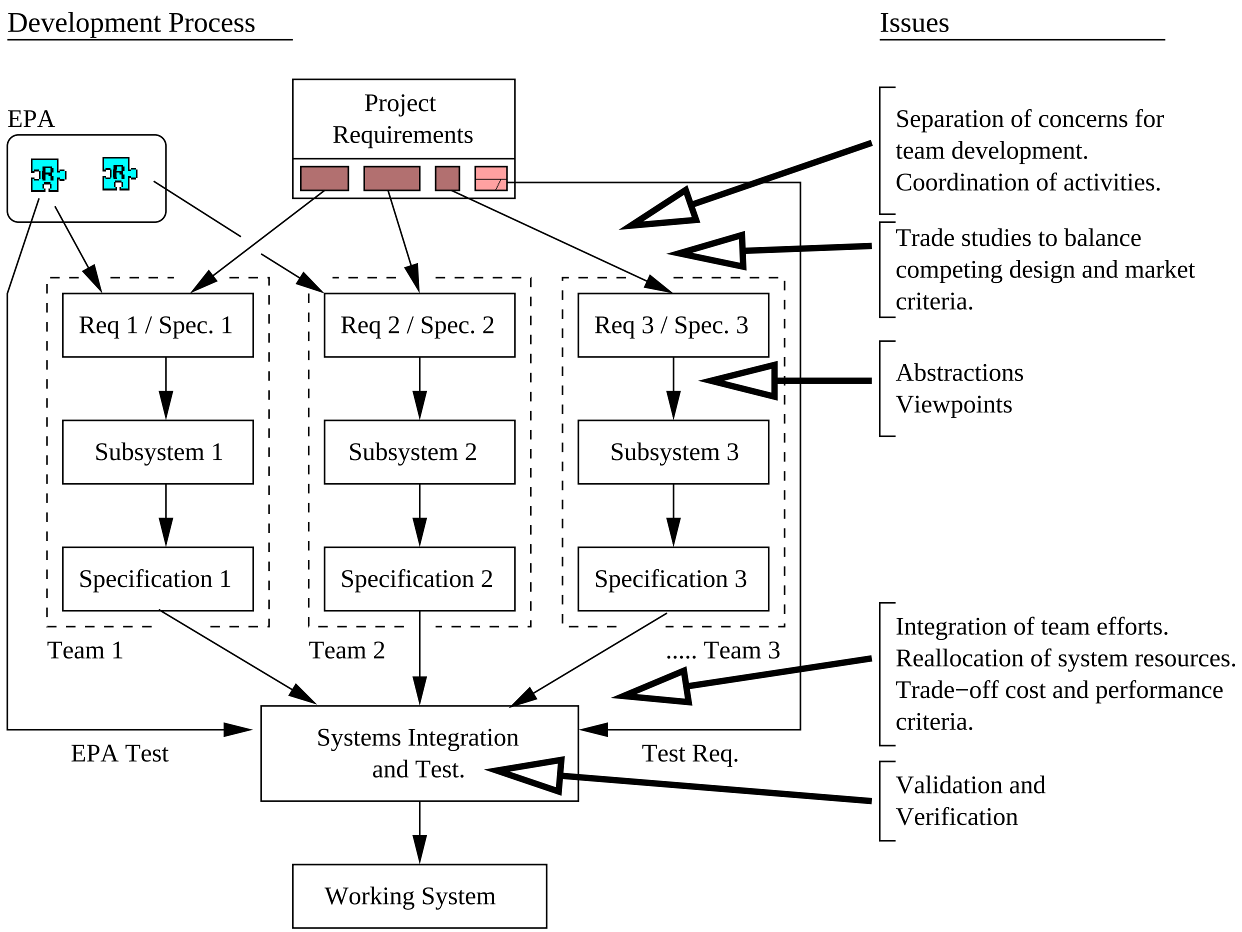


Focus on:

...liaison among disciplines, supported by formal methods for systems analysis and design.

SE at the Project Level

Systems are developed by teams of engineers – the team members must be able to understand one-another's work.

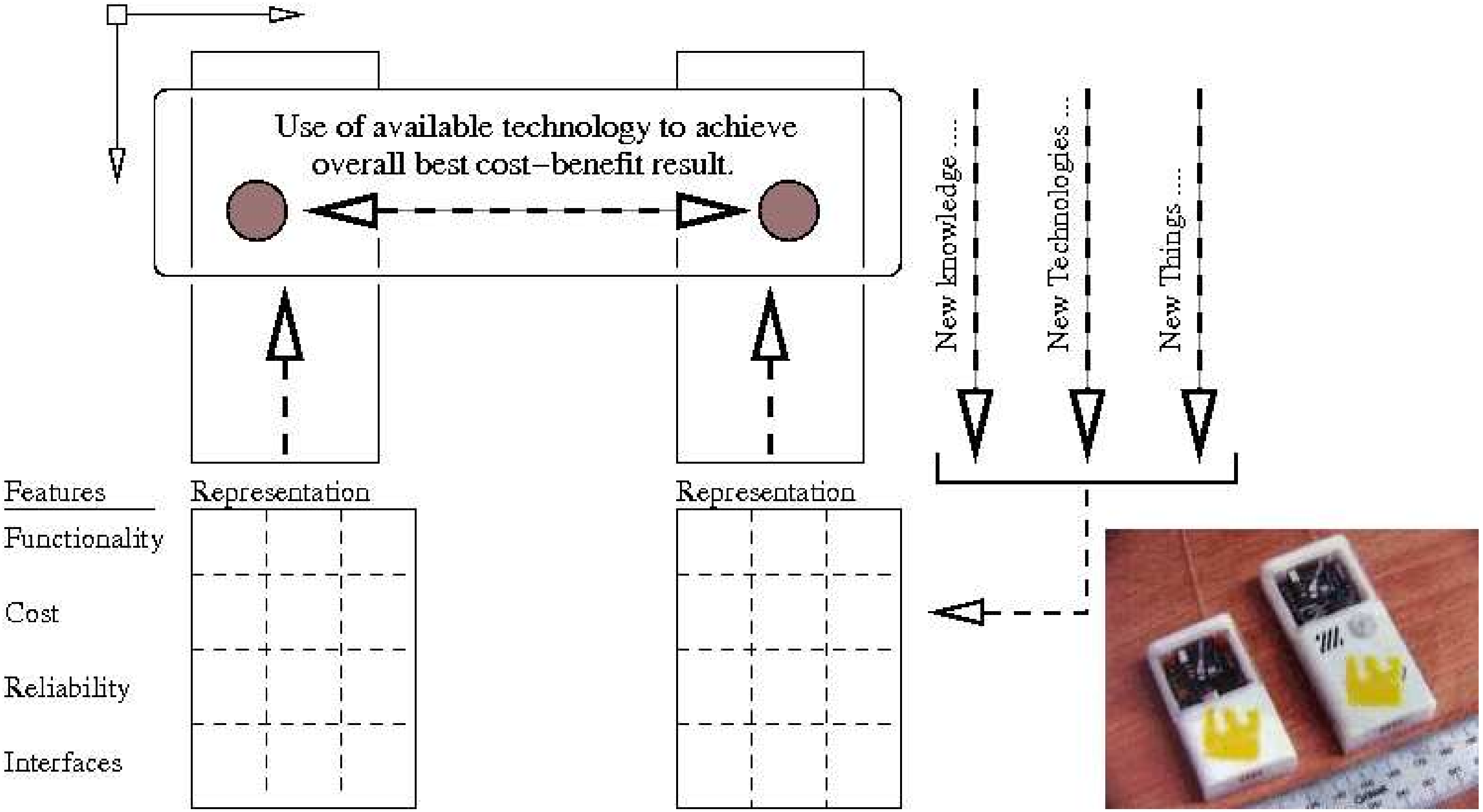


SE at the Project Level

Key concerns:

1. How to gather requirements that might extend beyond functionality, performance and cost (e.g., social concerns, political concerns, long-term sustainability)?
2. Partitioning of the design problem into several levels of abstraction and viewpoints suitable for concurrent development by design teams;
3. Synthesis of good design alternatives from modular components;
4. Integration of the design team efforts into a working system; and
5. Evaluation mechanisms that provide a designer with critical feedback on the feasibility of a system architecture, and make suggestions for design concept enhancement.
6. Formal methods for early validation/verification of systems.

SE at the Product Level



SE at the Product Level

Key concerns:

1. How to describe what a product does? Can this be done formally?
2. How to describe pre-conditions for using a product?
3. How to describe a products interfaces?
4. How to describe various representations (visual, mathematical).

End-to-End Lifecycle Development

Systems Engineering Development

Planning and Analysis	System Architecting	System Design	Build and Test
−− Create Project Concept −− Generate Requirements −− Validation	−− Function Analysis −− Requirements Analysis −− System Synthesis −− Validation −− Verification	−− Physical Design −− Tradeoff Analysis −− Validation −− Verification	−− Systems Integration −− Validation −− Verification

The principal products of systems engineering development are as follows:

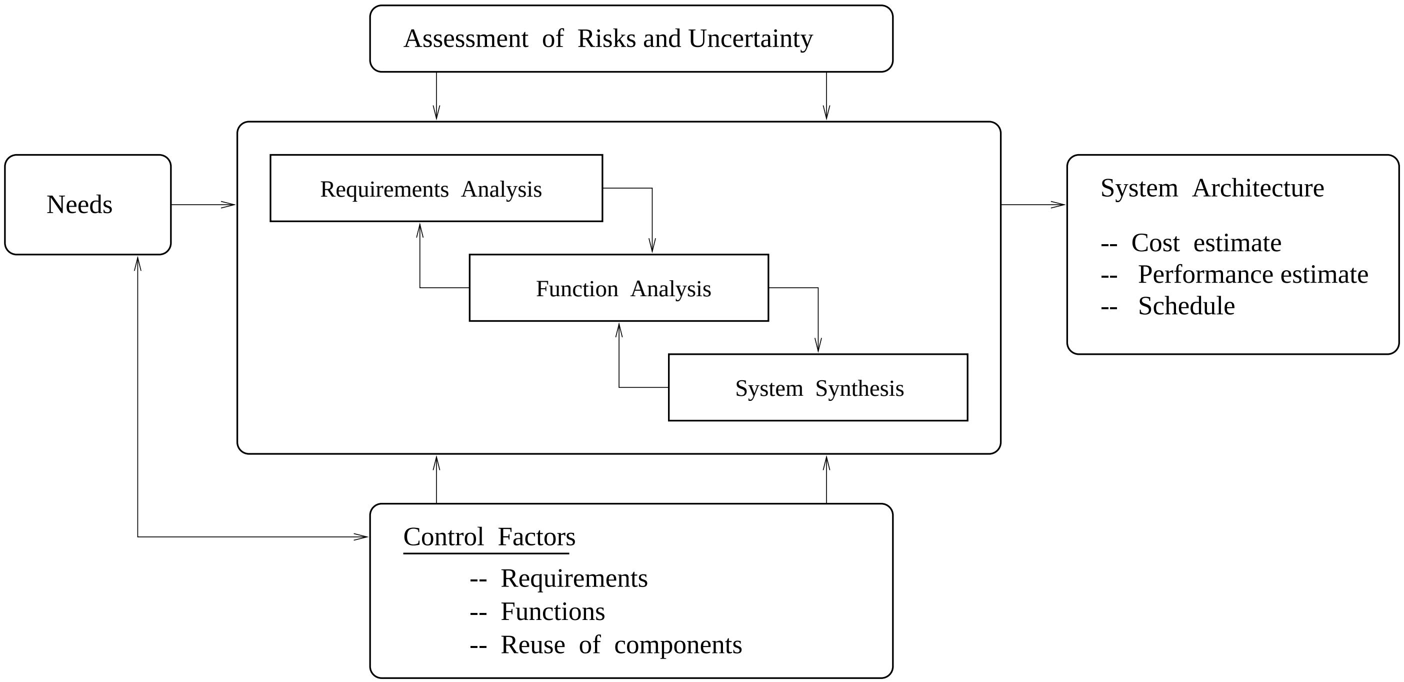
- Requirements specification; system (logical) architecture; system (physical) design; the physical system itself.

These products are produced by the following processes:

- Requirements engineering; system architecting; systems design and integration; optimization and trade-off analysis; validation and verification.

End-to-End Lifecycle Development

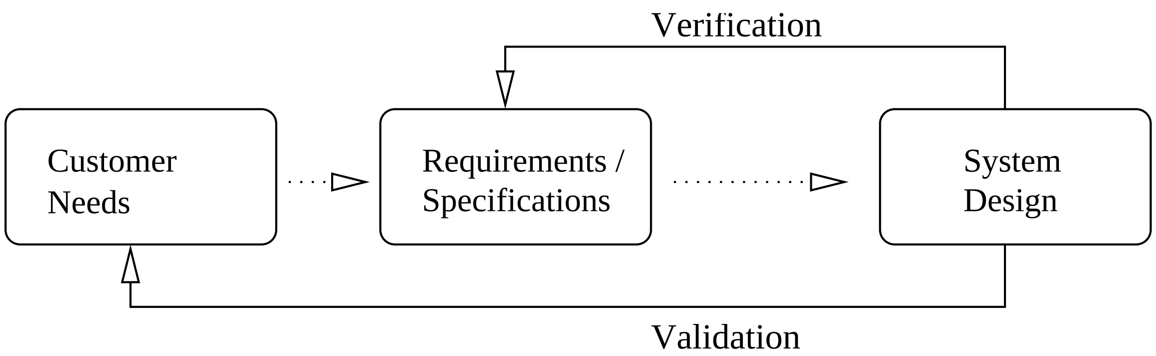
Technical process for system architecting.....



End-to-End Lifecycle Development

The terms system validation and verification refer to two basic concerns, “are we building the right product” and “are we building the product right?”

Satisfactory answers to both questions are a prerequisite to customer acceptance.



Validation and verification concerns are a prerequisite to customer acceptance.

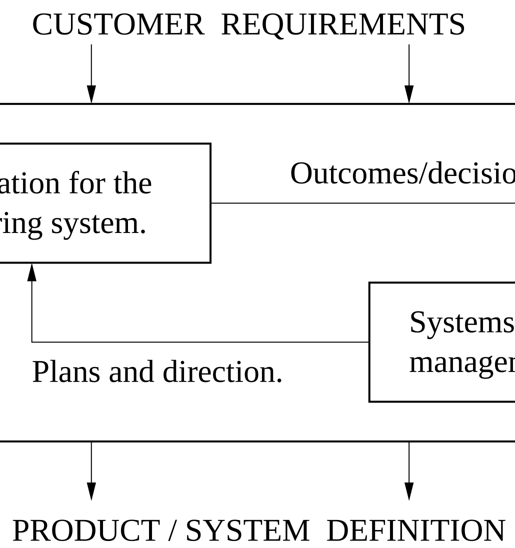
Systems Engineering Processes

Pre-defined plans of development ...

... provide the discipline to keep development activities predictable and on track.

The project participants know what's expected and when.

Interaction of technical development and engineering management processes



During the past 3-4 decades this approach to system development has served many industry sectors (e.g., aerospace) well.

Systems Engineering Processes

Engineering/Systems Engineering Activities and Artifacts

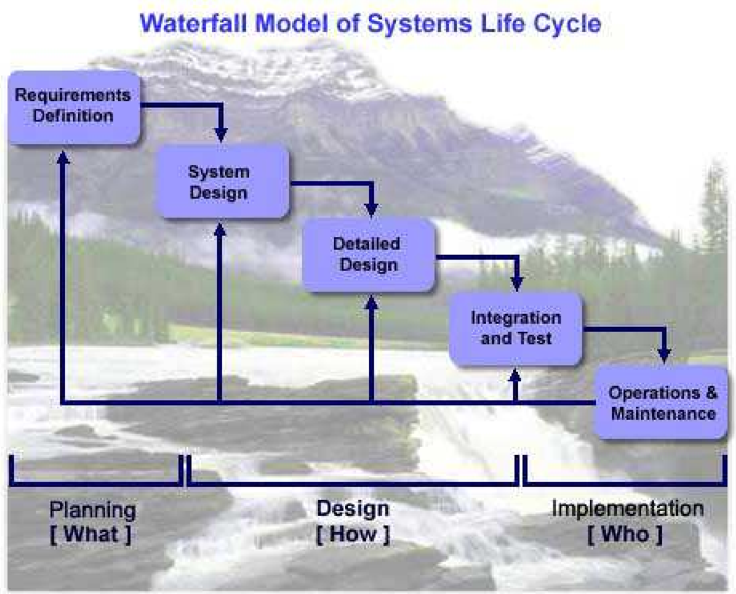
Engineering Activity	Systems Engineering	
	Activity	**Artifact**
Requirements Analysis	Requirements Analysis	Requirements baseline and specification.
Architecture	Function/behavior analysis	Logical Architecture.
Design	Synthesis	Physical Architecture and Design

Systems Engineering Processes

Systems Engineering Management Activities and Artifacts

Management Activity	Systems Management	
	Activity	**Artifact**
Requirements Management	Requirements Management	Requirements baseline and specification.
Configuration Management	Planning of activities and tasks. Communicate compliance status	Work products
Baseline Management	...	...

Waterfall Model of Development

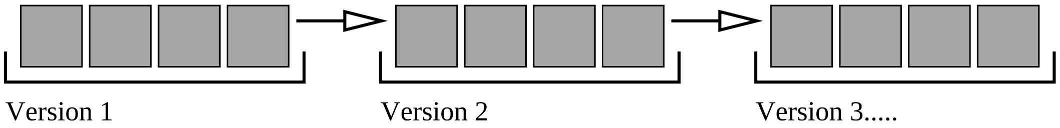


The waterfall model works well when:

... problem and solution method are well understood, requiring no large-loop corrections to development problems.

Iterations of Waterfall Development

Iterations of Waterfall Development.....

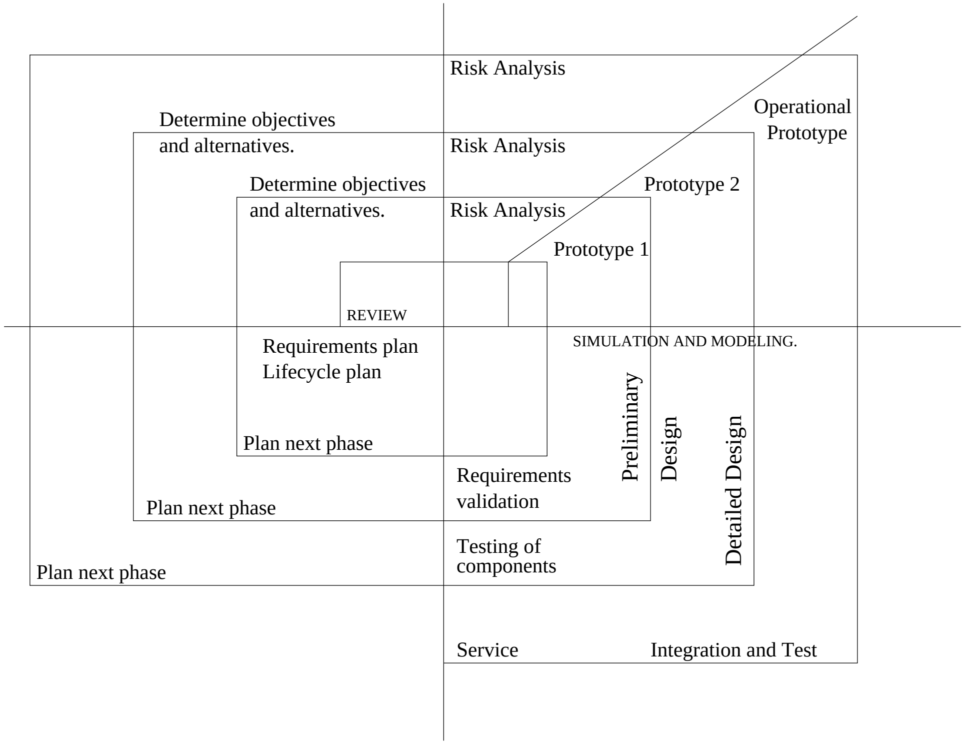


Limitations of Waterfall Model

- Changing requirements proved to be the biggest cause of cost overruns and schedule slips in the waterfall era.
- Users were found to be unable to define the requirements of a complex system without having had hands-on previous experience with the system – A Catch 22.

Spiral Model of Systems Development

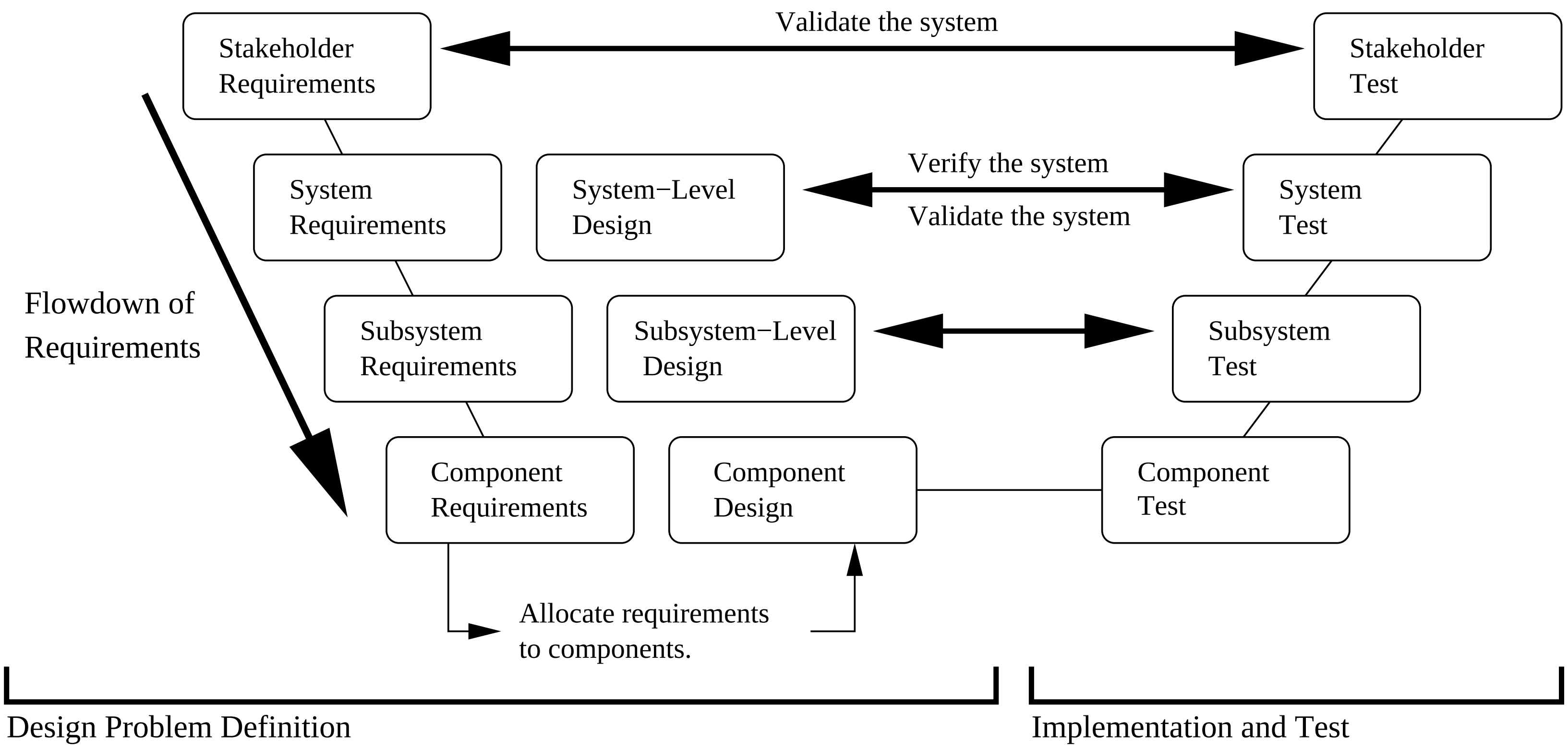
Spiral model corresponds to risk oriented iterative enhancement.



Categories of risk include: technical risk, schedule risk, cost risk, programmatic risk.

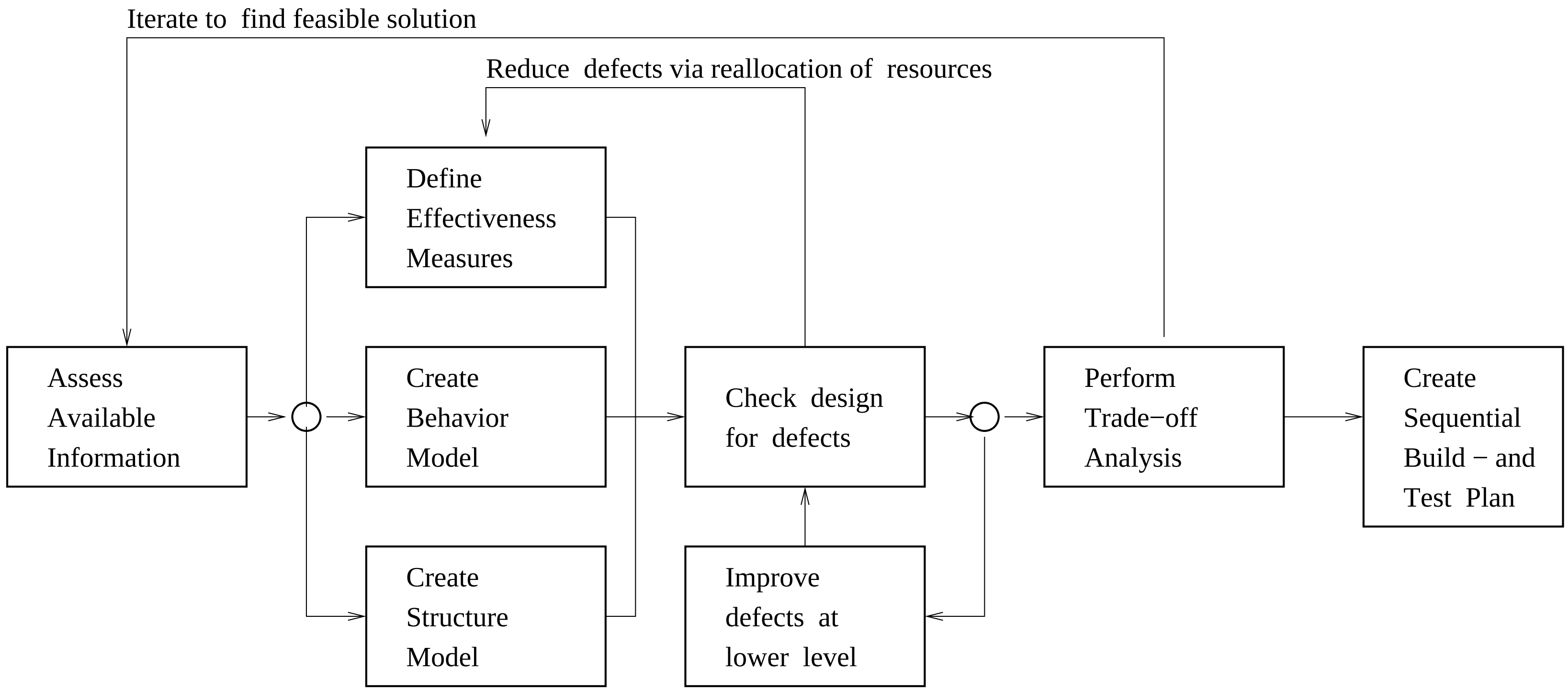
V-Model of Systems Development

Flowdown of requirements in the V-Model of system development.



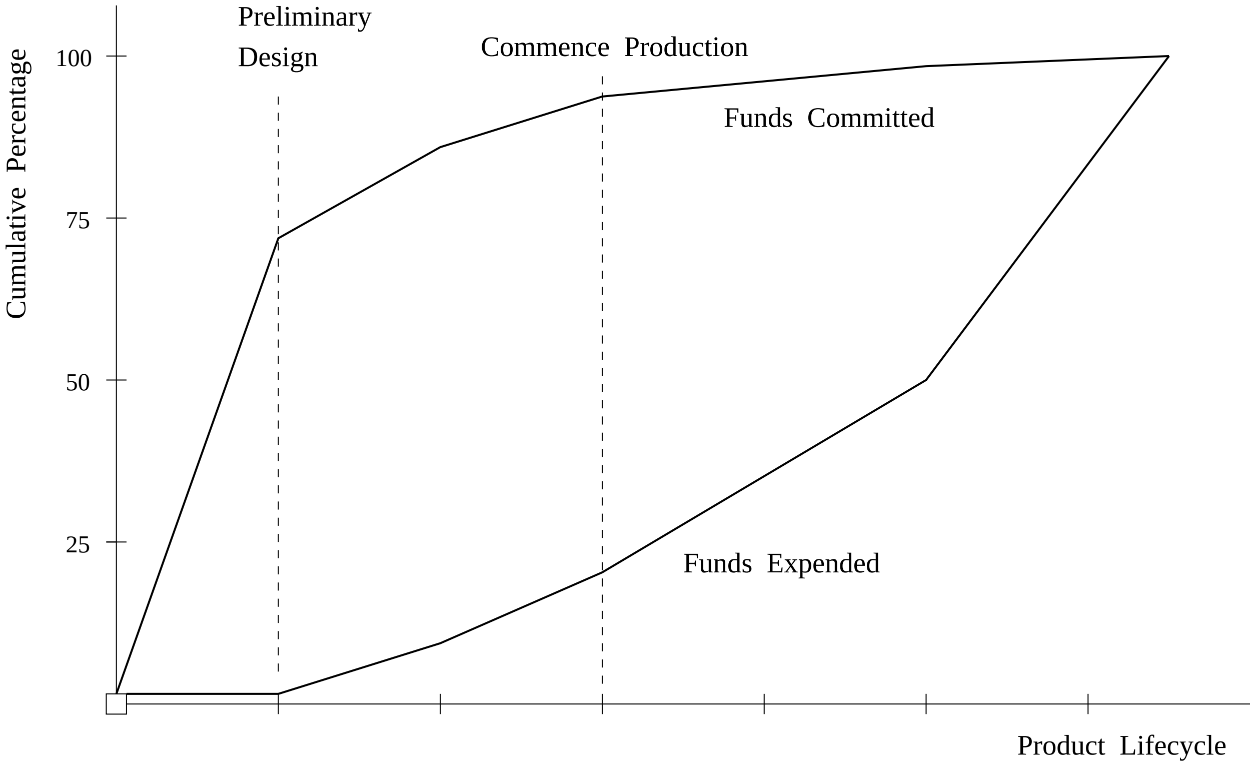
Systems Engineering at General Electric

Functional flow block diagram for the core technical process at GE.



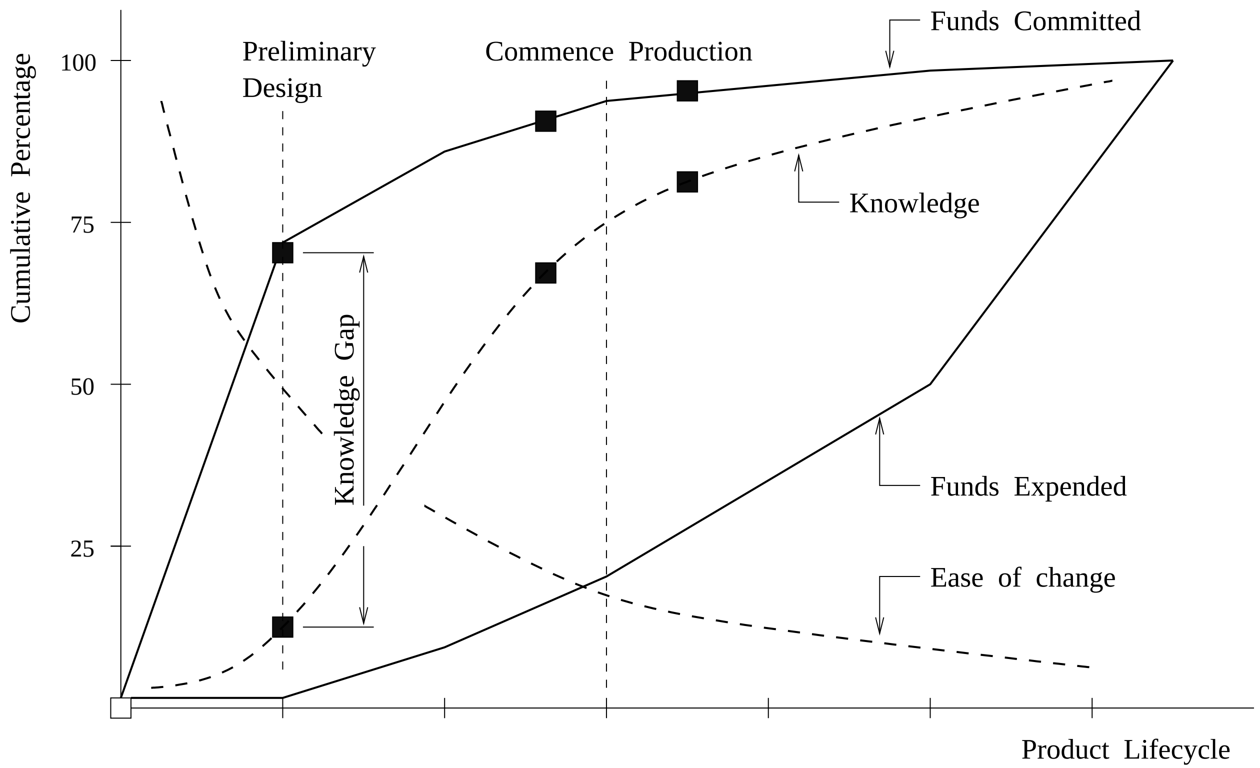
Economics of Development

Funding Commitments in Product Life-Cycle



Economics of Development

Knowledge Gap in Systems Development



Economics of Development

Cost of Correcting Design Errors

Project Phase	Bug Description	Relative Cost
Design	Design Team	1
Write and Test	Designer	10-20
Quality Assurance	QA Personnel	70-100
Shipment to Customer	Customer	Very-expensive