What is Systems Engineering?

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How many people in the room believe that systems engineering is defined by the Microsoft Certified Systems Engineer program???

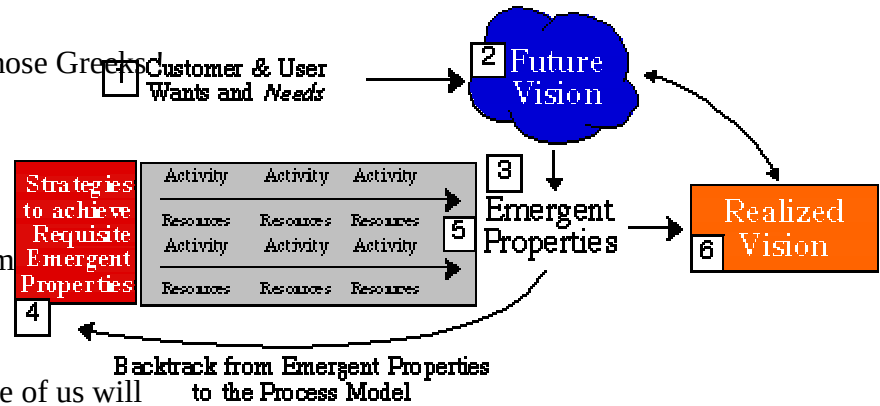
Topics

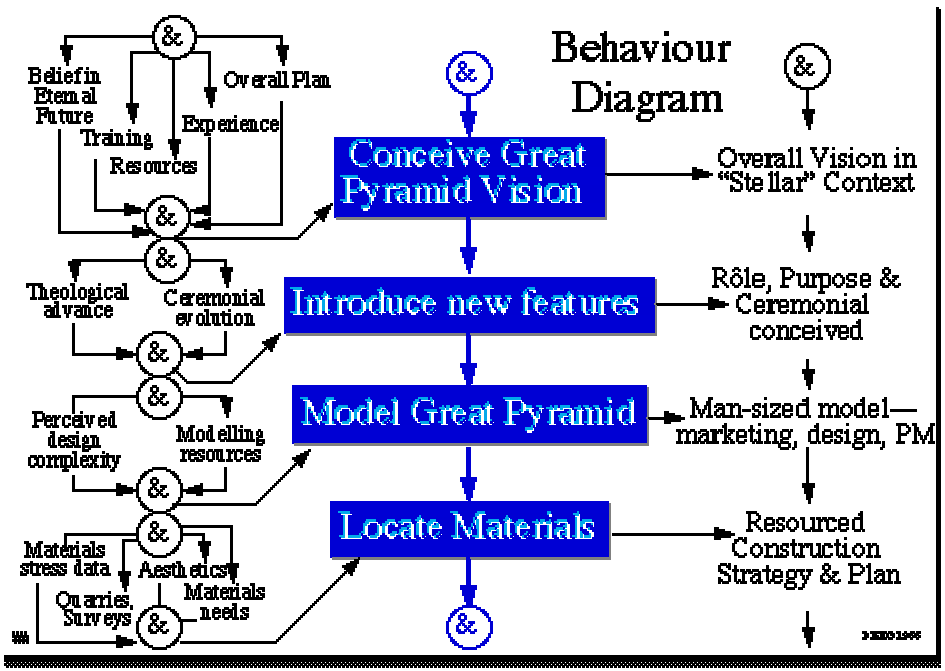
- Systems Engineering Roots
- What is a System?
- What is Systems Engineering?
- Systems Engineering Processes
- Value Proposition of Systems Engineering
- A Peek into the Future
- References

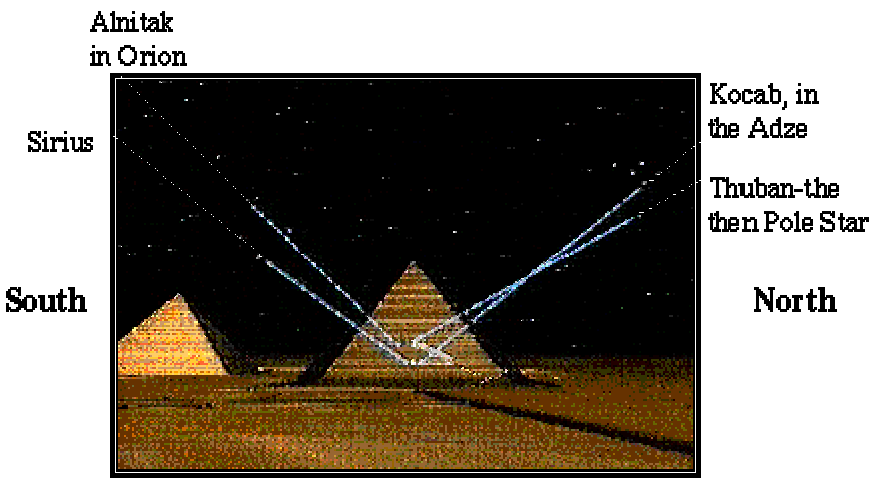
Systems Engineering Roots

Planning the Great Pyramid of Khufu...

- Reductionism has not yet been invented - c.2000 years to go before those Greeks
- Mercifully, Henry Ford and Taylorism have some 4,500 years to go !
- Happily, ancient Egyptians *instinct* was to build&emdash;so...
- "Big" was good, "Takes many years" was fine, "Cost" was no problem
- Not yet spoilt by conscious fear of failure and risk
- Still, Hemon dare not fail - "Egypt and Khufu must be eternal, or none of us will live for ever"







Hitchins 1997

What is a System?

INCOSE [1998]

> An integrated set of elements to accomplish a defined objective. These include hardware, software, firmware, people, information, techniques, facilities, services, and other support elements.

Hierarchy of system elements:

Element or segment	Subassembly
Subsystem	Component
Assembly	Part

What is a System?

Hall [1962]

A system is a set of objects with relationships between the objects and between their attributes.

Objects - parts of components of the system

Attributes - properties of objects, e.g.,

- Stars - temperature, distances from other stars
- Switches - speed of operation, state
- Springs - spring tension, displacement
- Wires - tensile strength, electrical resistance

Relationships tie the system together

Causal Logical Random

Environment

For a given system, the environment is the set of all objects outside the system: (1) a change in whose attributes affect the system and (2) whose attributes are changed by the behavior of the system.

What is a System?

Kauffman [1980]

A system is a collection of parts which interact with each other to function as a whole.

Types of systems:

Mechanical	Human/mechanical	Biological
Ecological	Social	

Characteristics of complex systems:

Self-stabilizing	Environment modifying
Goal-seeking	Self-replicating
Program-following	Self-maintaining and repairing
Self-reprogramming	Self-reorganizing
Anticipation	Self-programming

Problems of complexity:

Tragedy of the commons	Cost of information
Distortion of feedback	Loss of predictability

What is a System?

Martin [1997]

A system is a set of integrated end products and their enabling products.

The end products and enabling products of a system are composed of one or more of the following:

hardware	data
software	materials
personnel	services
facilities	techniques

What is a System?

Hitchins [1997]

A set of complementary, interacting parts with properties, capabilities and behaviours emerging both from the parts and from their interactions

Perhaps the key feature of the definition is the word "interactions".

- What distinguishes a System from a pile of bits is simply that, in a system, the parts interact with each other to produce "properties, capabilities and behaviours".
- So, while a pile of bits has properties - mass, volume, etc. - none of them emerges because of interactions between the bits.

Why is this important?

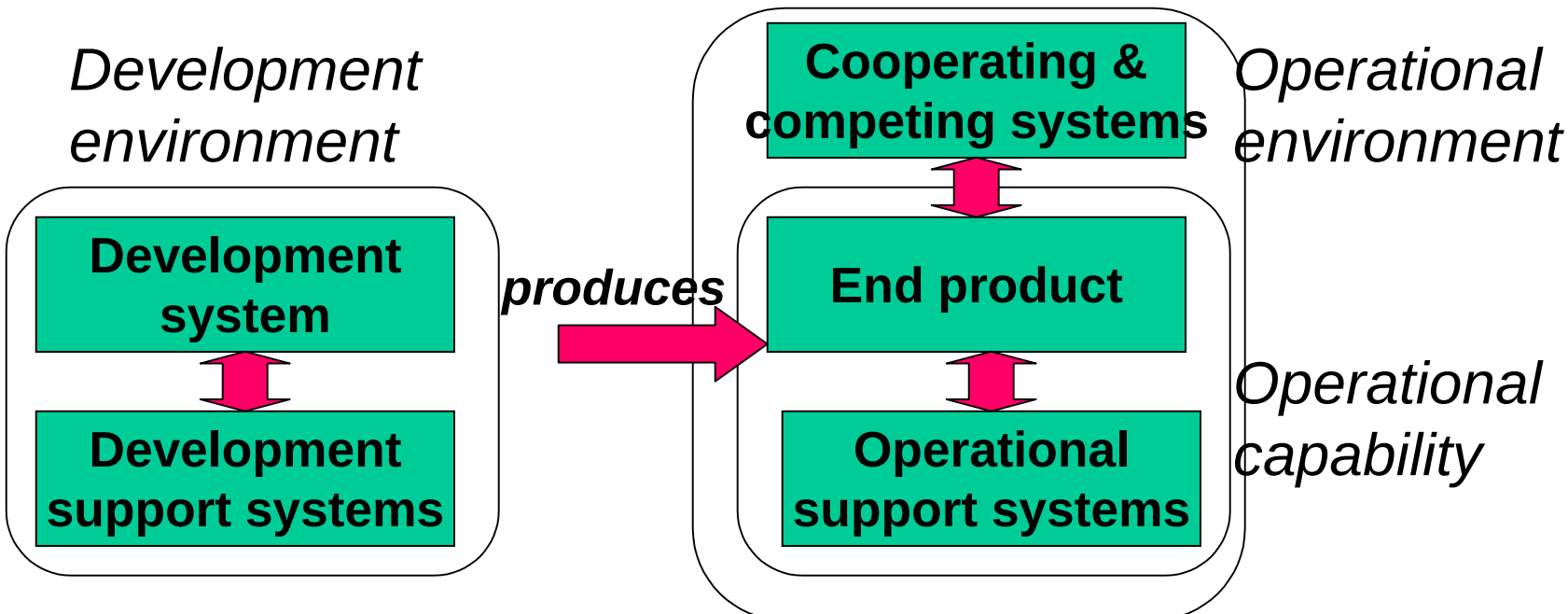
- Because of the interactions, a system is complex, systems may be able to do things, to exhibit behaviour, to have system capabilities that none of their parts has.

What is a System?

Stevens, Brook, Jackson and Arnold [1998]

System often used synonymously with a product

- Product is an artefact (a human-made entity with a distinguishing and identifiable purpose) that draws on integrated, constituent parts, each of which does not individually possess the required overall characteristics.
- Making an end product needs development support systems (including infrastructure and a test system), and perhaps a system to install or mass-produce the product.



What is Systems Engineering?

INCOSE [1998]

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

Operations	Cost & Schedule
Performance	Training & Support
Test	Disposal
Manufacturing	

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

What is Systems Engineering?

INCOSE SE Handbook [1998]

> An interdisciplinary approach and means to enable the realization of successful systems.

Forrester [1961]

> Systems engineering is a formal awareness of the interactions between the parts of a system.

Hall [1962]

> Operates in the space between research and business, and assumes the attitudes of both. It considers the needs of its customers and determines how these can be best met in the light of all knowledge both old and new. It formulates the operational, performance and economic objectives, and the broad technical plan to be followed.

What is Systems Engineering?

Martin [1997]

Systems Engineering consists of three elements:

SE Management Process

Plans, organizes, controls and directs the technical development of a system or its products

Requirements and Architecture Definition

Defines the technical requirements based on the stakeholder requirements, defines a structure (or an architecture) for the system components, and allocates these requirements to the components of this architecture

System Integration and Verification

Integrates the components of the architecture at each level of the architecture and verifies that the requirements for those components are met

What is Systems Engineering?

Hitchins [1997]

The Art and Science of Creating Effective Systems, using Whole System, Whole Life Principles

Whole System Principles

First Principle of Systems:

The properties, capabilities and behaviors of a system derive both from its parts and from the interactions between those parts.

Corollary to the First Principle:

Altering the properties or behavior of any of the parts, or any of their interactions, affects other parts, the whole system, and interacting systems.

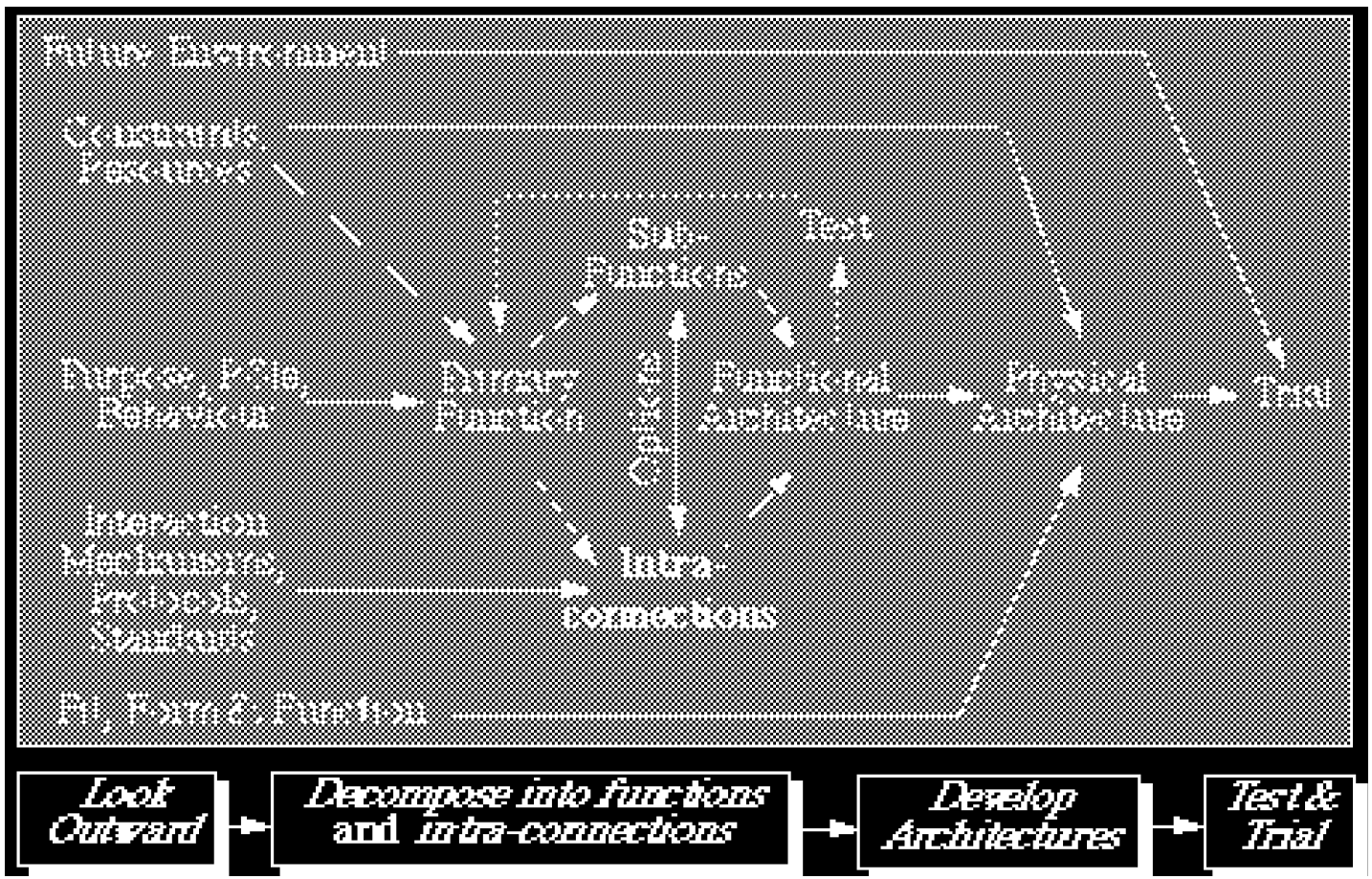
Systems Engineering is not:

Piecemeal development or systematic engineering

What is Systems Engineering?

Hitchins [1997]

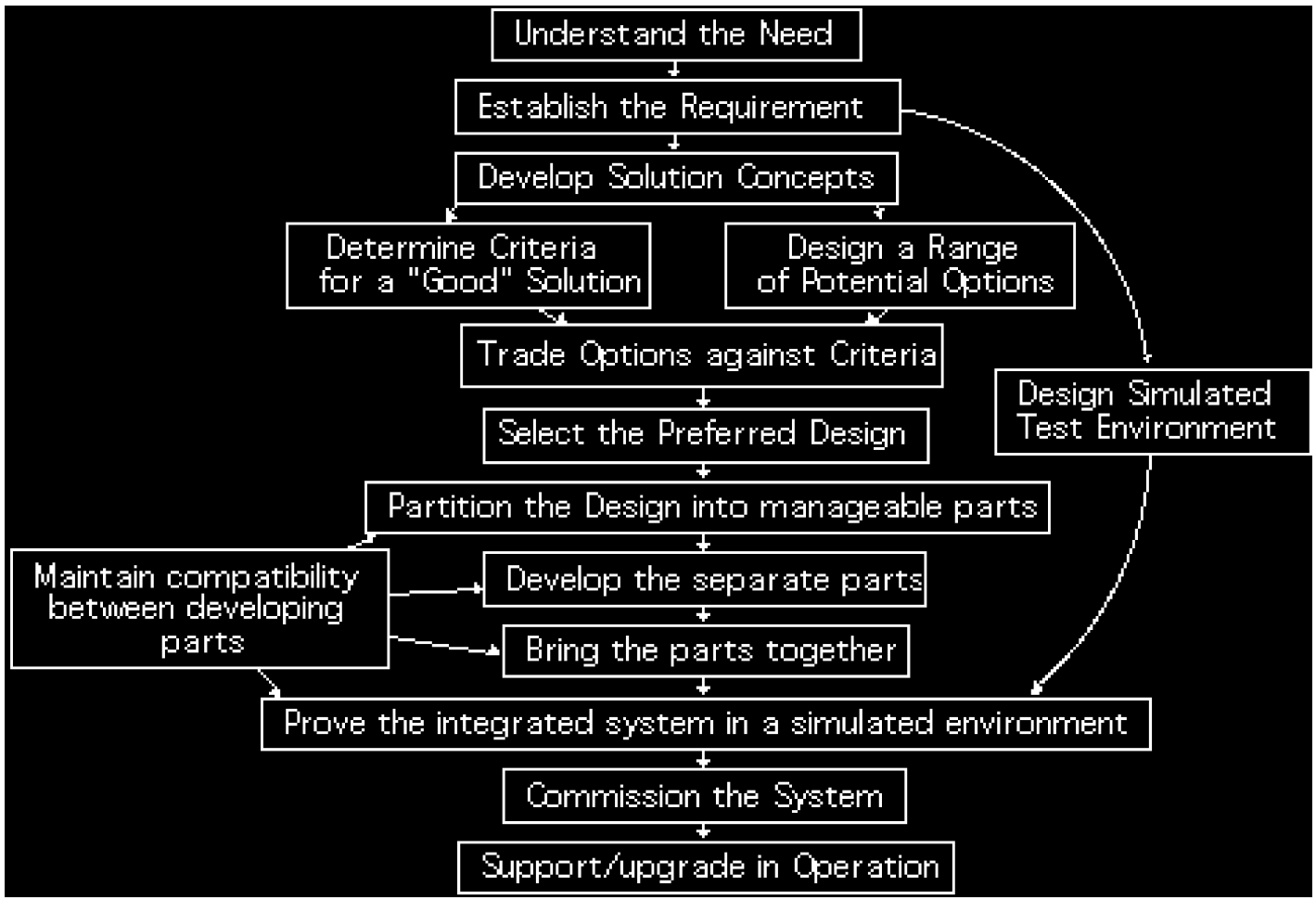
Layer 1 Product Systems Engineering



What is Systems Engineering?

Hitchins [1997]

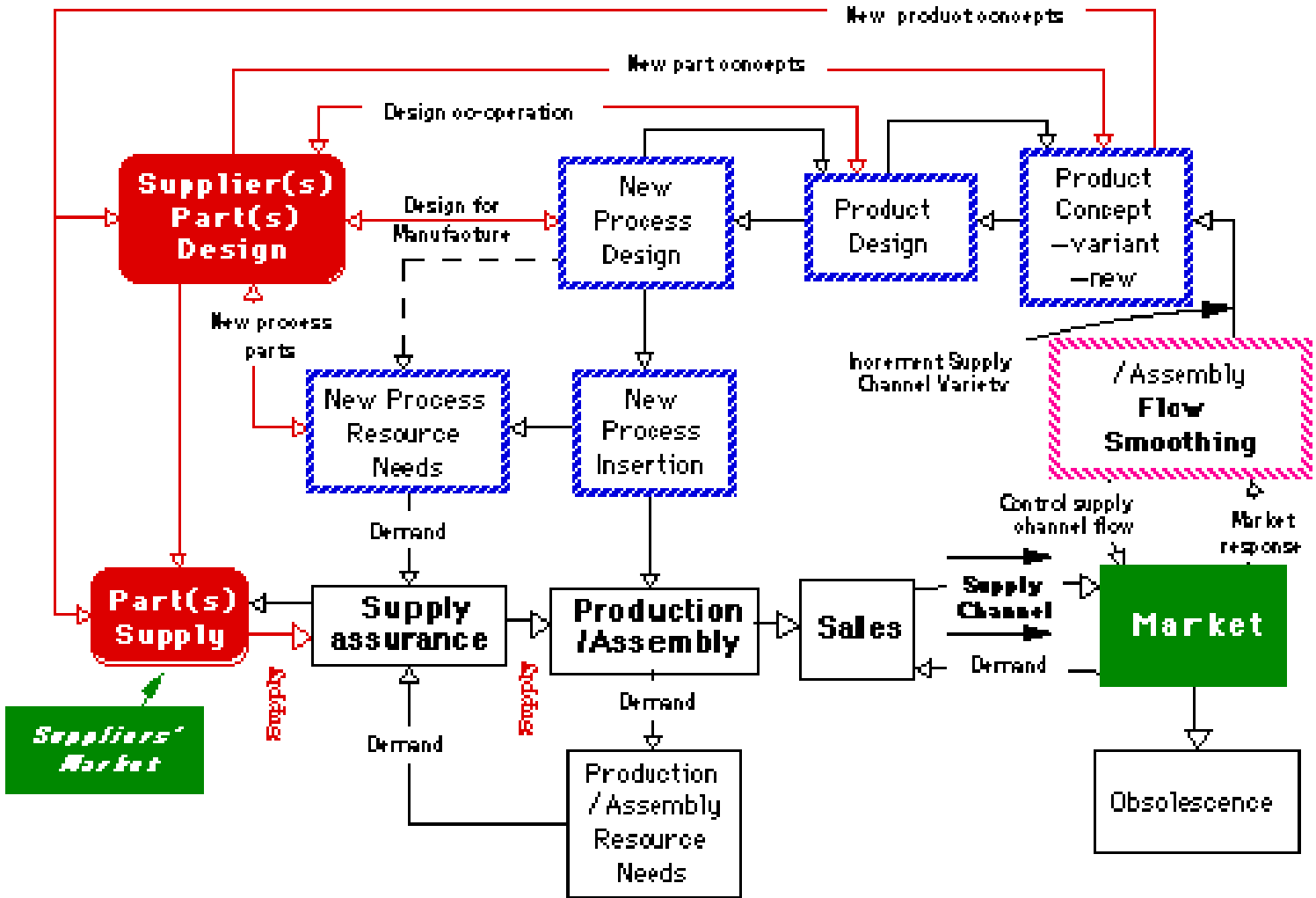
Layer 2 Project Systems Engineering



What is Systems Engineering?

Hitchins [1997]

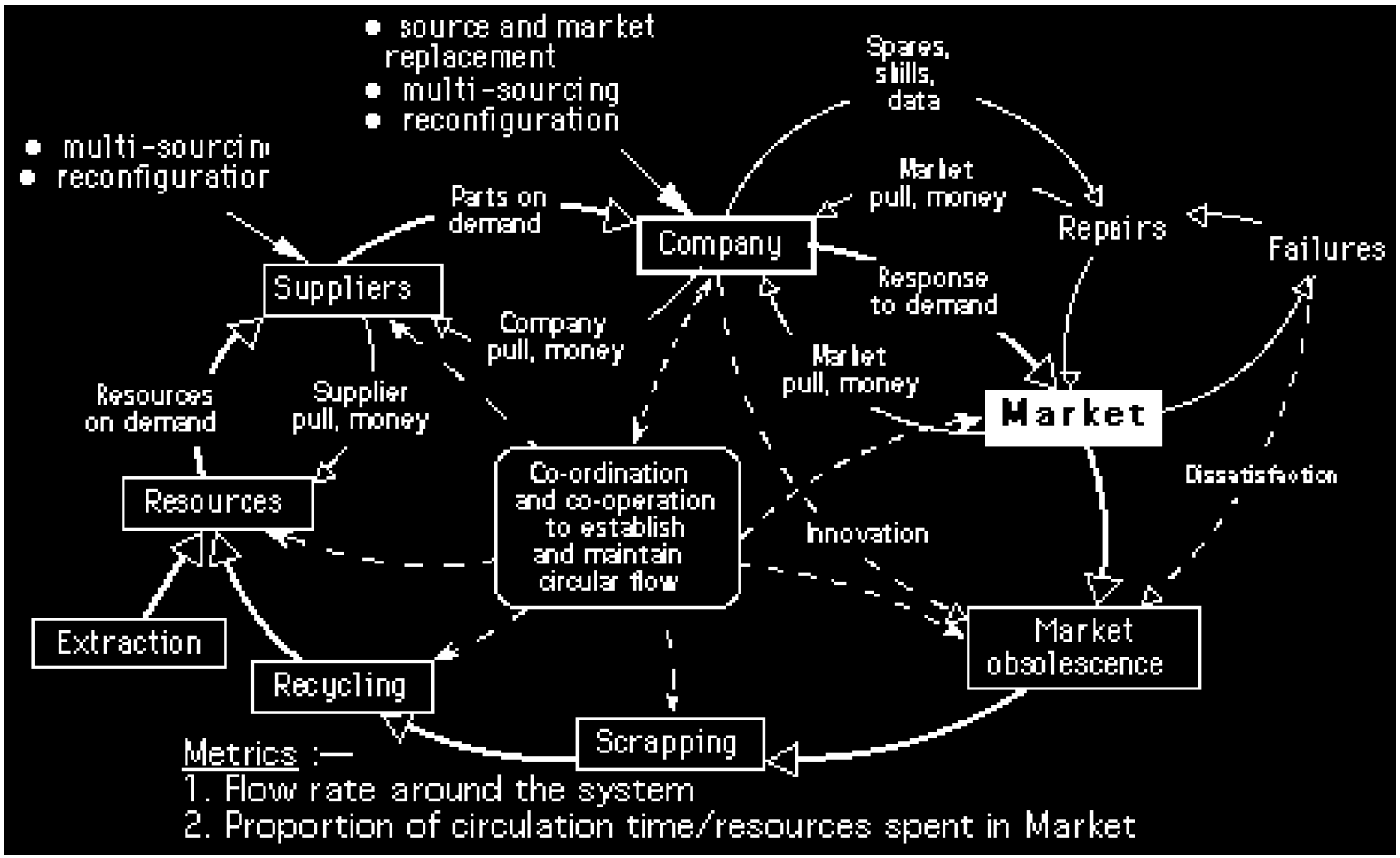
Layer 3 Business Systems Engineering



What is Systems Engineering?

Hitchins [1997]

Layer 4 Industrial or Supply Chain Systems Engineering



What is Systems Engineering?

Hitchins [1997]

Layer 5 Socio-Economic Systems Engineering

Raw Materials Industries	•Energy •Metals • Woods • Plastic • Composites	▪ Dated skills	▪ Domestic Raw Materials	▪ Fertilizers
▪ Machinery ▪ Knowledge ▪ Power	**Manufacturing Industries**	▪ Dated skills ▪ Power ▪ Machines	▪ Domestic products/ materials	▪ Farm machinery ▪ Power
• Skilled people •Recycleable raw material	• Skilled people • Logistics • Recycleable machinery	**Service Industries**	• Power • Food • Distribution • Transport • Communication	• Power • Fertilizers • Pesticides • Husbandry
▪ Human resources	▪ Human resources	▪ Human resources ▪ Dated skills	**Society**	▪ Human resources
▪ Recycleable resources	▪ Recycleable machinery	▪ Foodstuffs ▪ Dated Skills	▪ Food	**Farming Industries**

What is Systems Engineering?

Stevens, Brook, Jackson, and Arnold [1998]

Systems engineering is about creating effective solutions to problems, and managing the technical complexity of the resulting developments.

At the outset, it is a creative activity, capturing, defining, and organizing the requirements and the product to be built.

Systems engineering creates the architecture.

Then the emphasis switches again, to integration and verification, before delivering the system to the customer.

Determines trade-offs between competing factors such as performance, risk and cost.

Provides the framework for the work of the other disciplines.

Provides technical coordination.

Systems Engineering Process

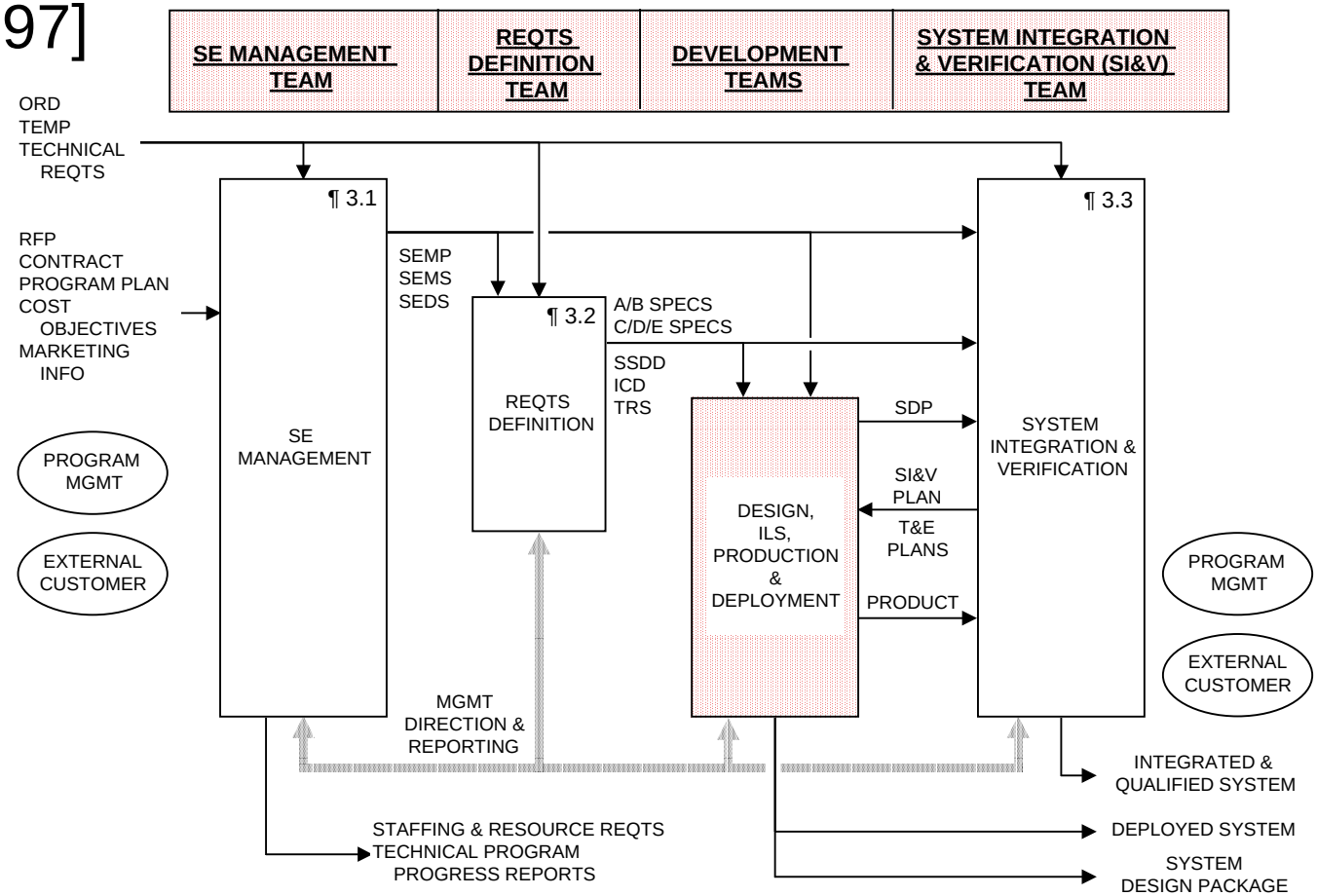
Hall [1962]

Phases

- Systems Studies
- Exploratory Planning
  - Problem definition
  - Selecting objectives
  - Systems synthesis
  - Systems analysis
  - Selecting the best system
  - Communicating results
- Development Planning
- Studies During Development
- Current Engineering

Systems Engineering Process

Martin [1997]

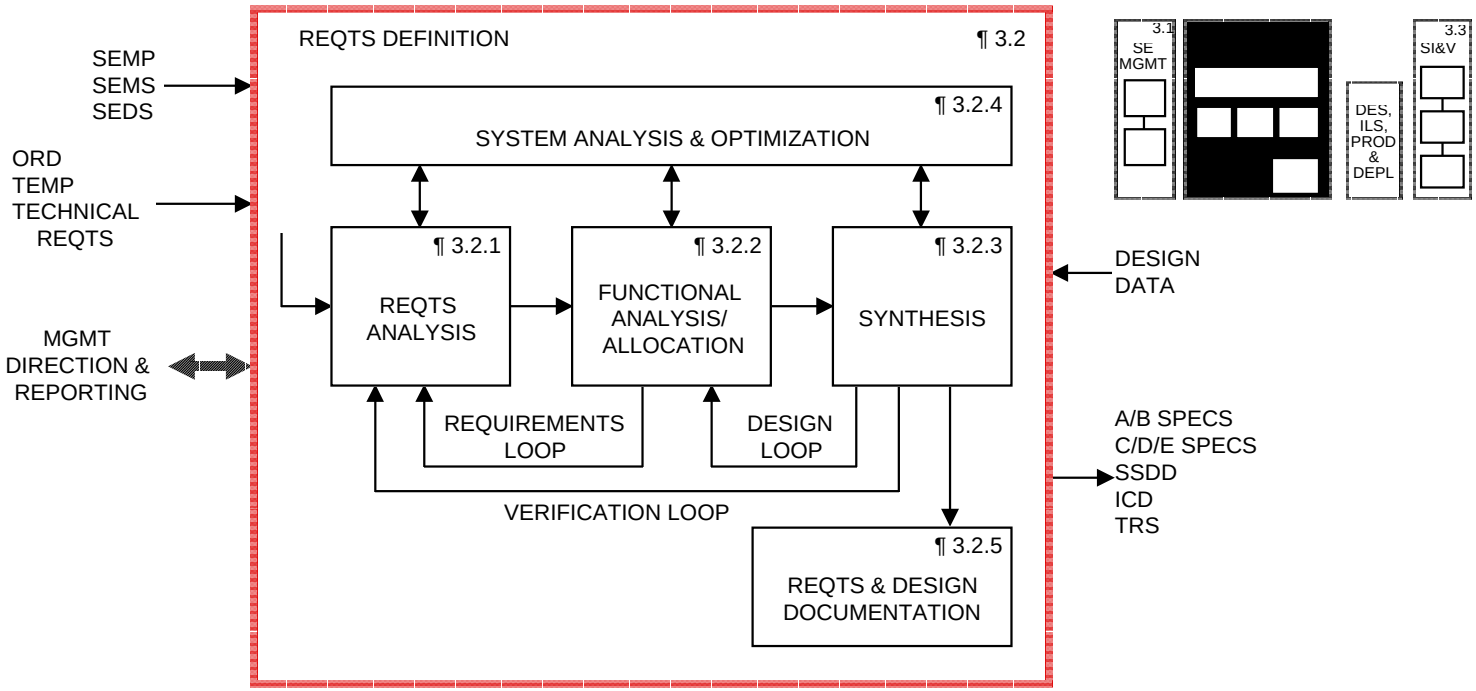


ILS	INTEGRATED LOGISTICS SUPPORT
RFP	REQUEST FOR PROPOSAL
SDP	SOFTWARE DEVELOPMENT PLAN
SEDS	SYSTEMS ENGINEERING DETAILED SCHEDULE
SEMP	SYSTEMS ENGINEERING MANAGEMENT PLAN
SEMS	SYSTEMS ENGINEERING MASTER SCHEDULE
T&E	TEST AND EVALUATION
TEMP	TEST AND EVALUATION MASTER PLAN

ORD	OPERATIONAL REQTS DOCUMENT
A SPEC	SYSTEM FUNCTIONAL REQTS
B SPEC	ALLOCATED DEVELOPMENT REQTS
C SPEC	PRODUCT FUNCTION/FABRICATION REQTS
D SPEC	PROCESS REQTS
E SPEC	MATERIAL REQTS
SSDD	SYSTEM/SEGMENT DESIGN DOCUMENT
ICD	INTERFACE CONTROL DOCUMENT
TRS	TEST REQTS SPECIFICATION

Systems Engineering Process

Martin [1997]



SEMP	SYSTEMS ENGINEERING MANAGEMENT PLAN	C SPEC	PRODUCT FUNCTION/FABRICATION REQTS
SEMS	SYSTEMS ENGINEERING MASTER SCHEDULE	D SPEC	PROCESS REQTS
TEMP	TEST AND EVALUATION MASTER PLAN	E SPEC	MATERIAL REQTS
ORD	OPERATIONAL REQTS DOCUMENT	SSDD	SYSTEM/SEGMENT DESIGN DOCUMENT
A SPEC	SYSTEM FUNCTIONAL REQTS	ICD	INTERFACE CONTROL DOCUMENT
B SPEC	ALLOCATED DEVELOPMENT REQTS	TRS	TEST REQTS SPECIFICATION

Systems Engineering Process

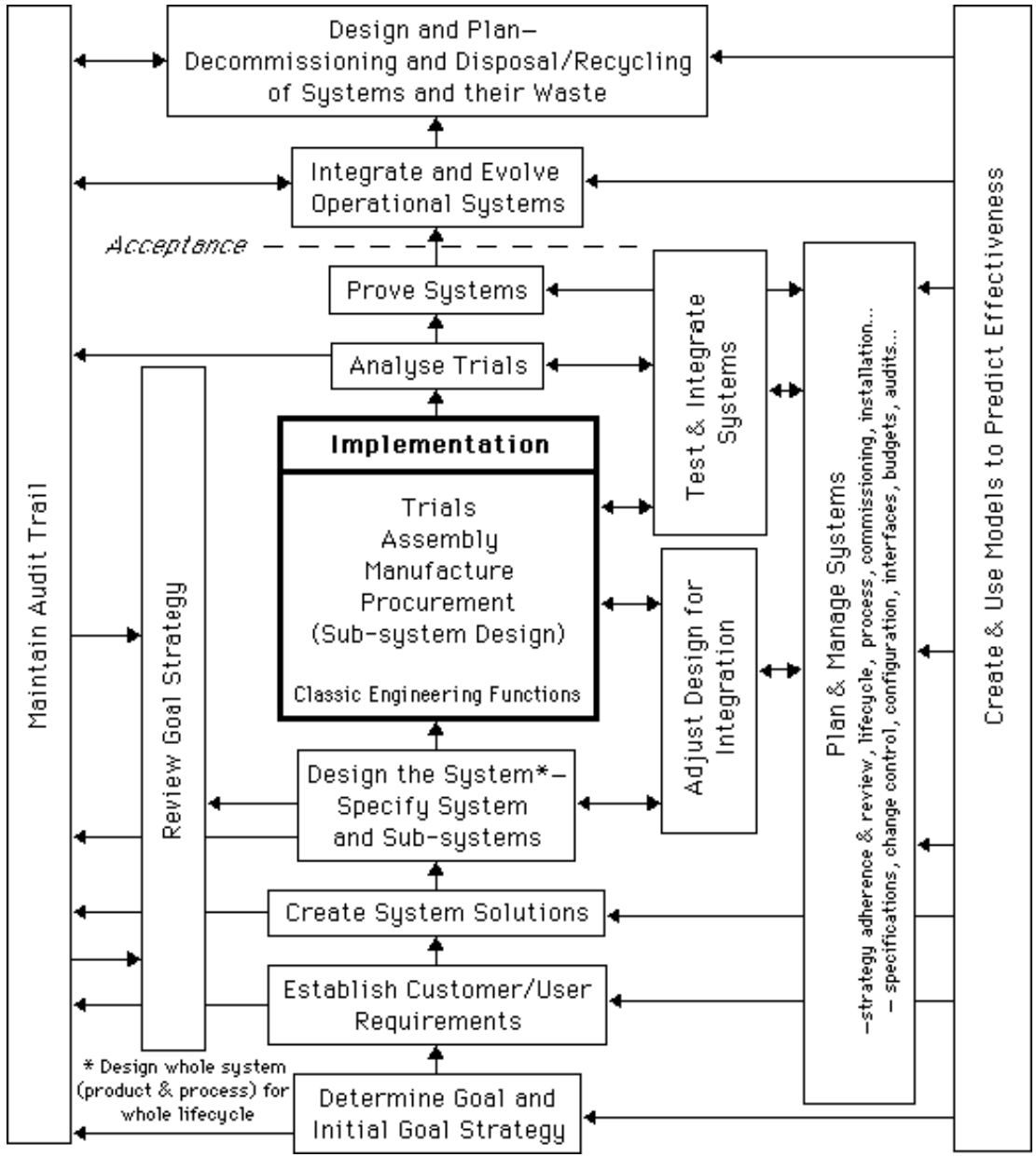
Hitchins [1998]

Layer 2

Project

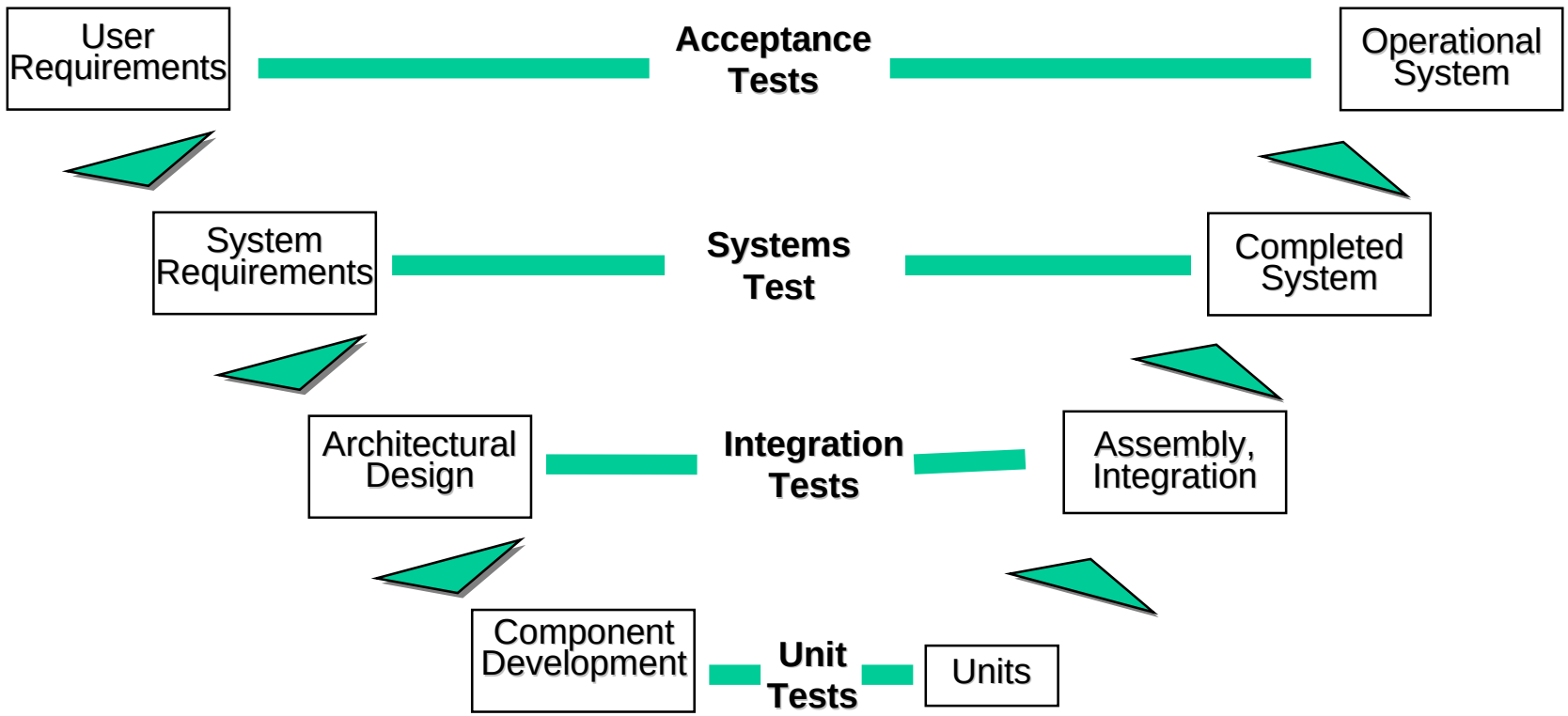
Systems

Engineering



Systems Engineering Process

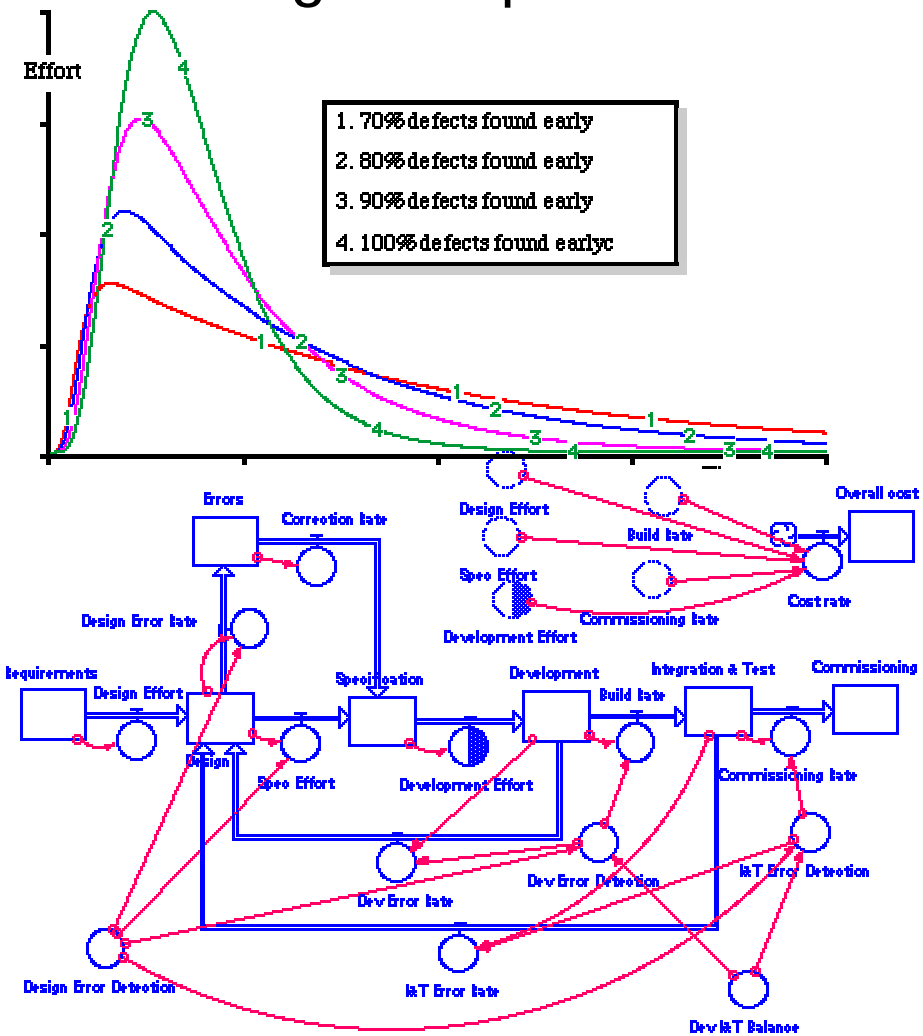
Stevens, Brook, Jackson, and Arnold [1998]



Process performed in iterative or spiral fashion across stage gates

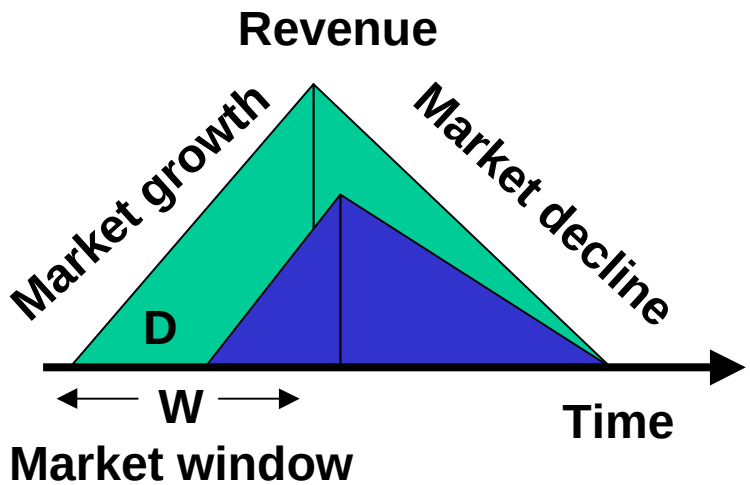
Value Proposition of Systems Engineering

The Right Requirements



Hitchins 1997

In the Market Window



Formula for revenue loss

$$\frac{D(3W-D)}{2W^2}$$

Market window W
Product life cycle 2W
Delayed market entry D

Carter & Baker 1992

A Peek Into the Future

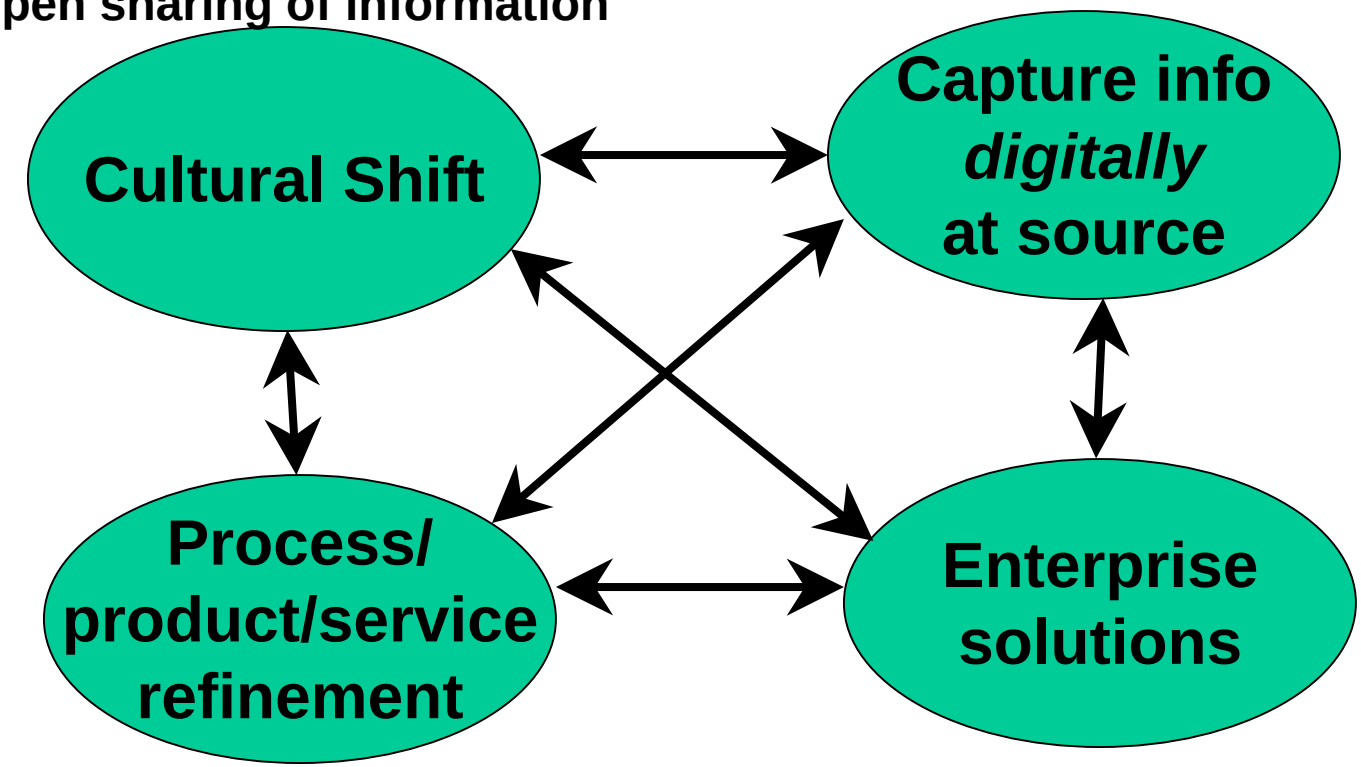
- Semiconductor component density doubles every 18 months [Moore's Law]
- Transmission capacity of fiber optics doubles every 12 months
- Disk storage doubling every 9 months
- Wireless capacity set to rapidly expand with 3G technology
- Although the cost of deploying a network increases linearly with the number of nodes in the network, the potential value of a network increases (scales) as a function of the square of the number of nodes that are connected by the network [Metcalfe's Law]
- Data traffic over the Internet is currently doubling every 7.5 months
- Mapping of the human genome

Implications for Systems Engineering

- eCommerce, eBusiness, eEverything
- More complex systems with complex interfaces
- Emphasis on systems thinking (Peter Senge)
- Integrative design rather than interdisciplinary design
- Model-based systems engineering
  - All requirements, and rationale behind them, accessible to designers
  - Completeness of design assessed by traceability
  - Consistent views of requirements, no disconnects among representations of data
  - Corporate memory of project retained
  - Simulation to execute actual behavior
- Systems engineering tools enabling state of the art practice

Keeping Pace in the Face of Complexity

Perception that time is critical
Open sharing of information

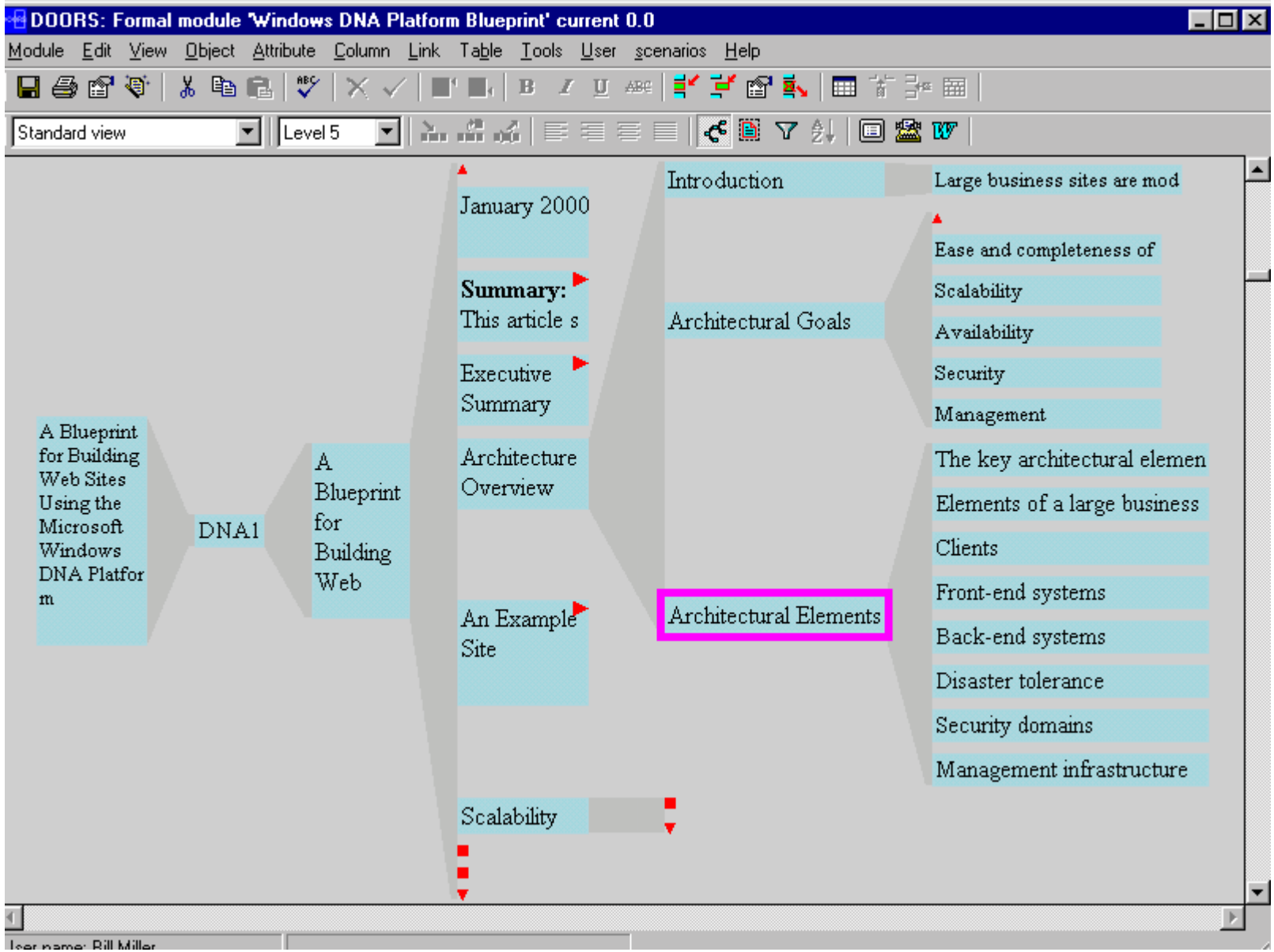


Customers
suppliers
processes
practices
procedures
products
services
financial
HR
competitors
markets
regulatory

Build on previous work
Technology enables new processes

Instill rigor and standardization

Systems Engineering Tools



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