Headquarters U.S. Air Force

Integrity - Service - Excellence

"Do It Right, Do It Early; Do It Early, Do It Right"

Considerations for the Early Stages of Concept, System, and System-of-Systems Definition

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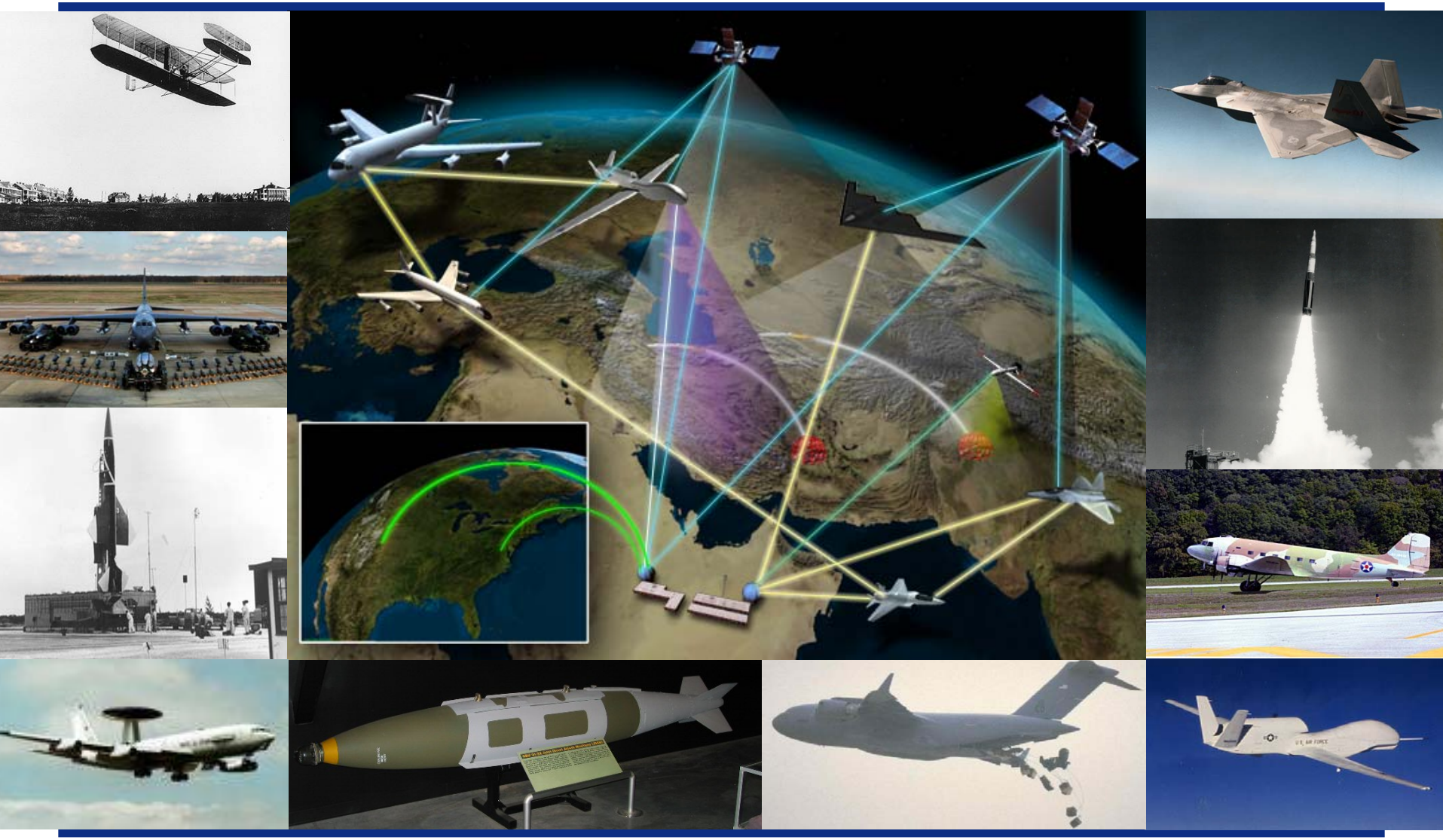
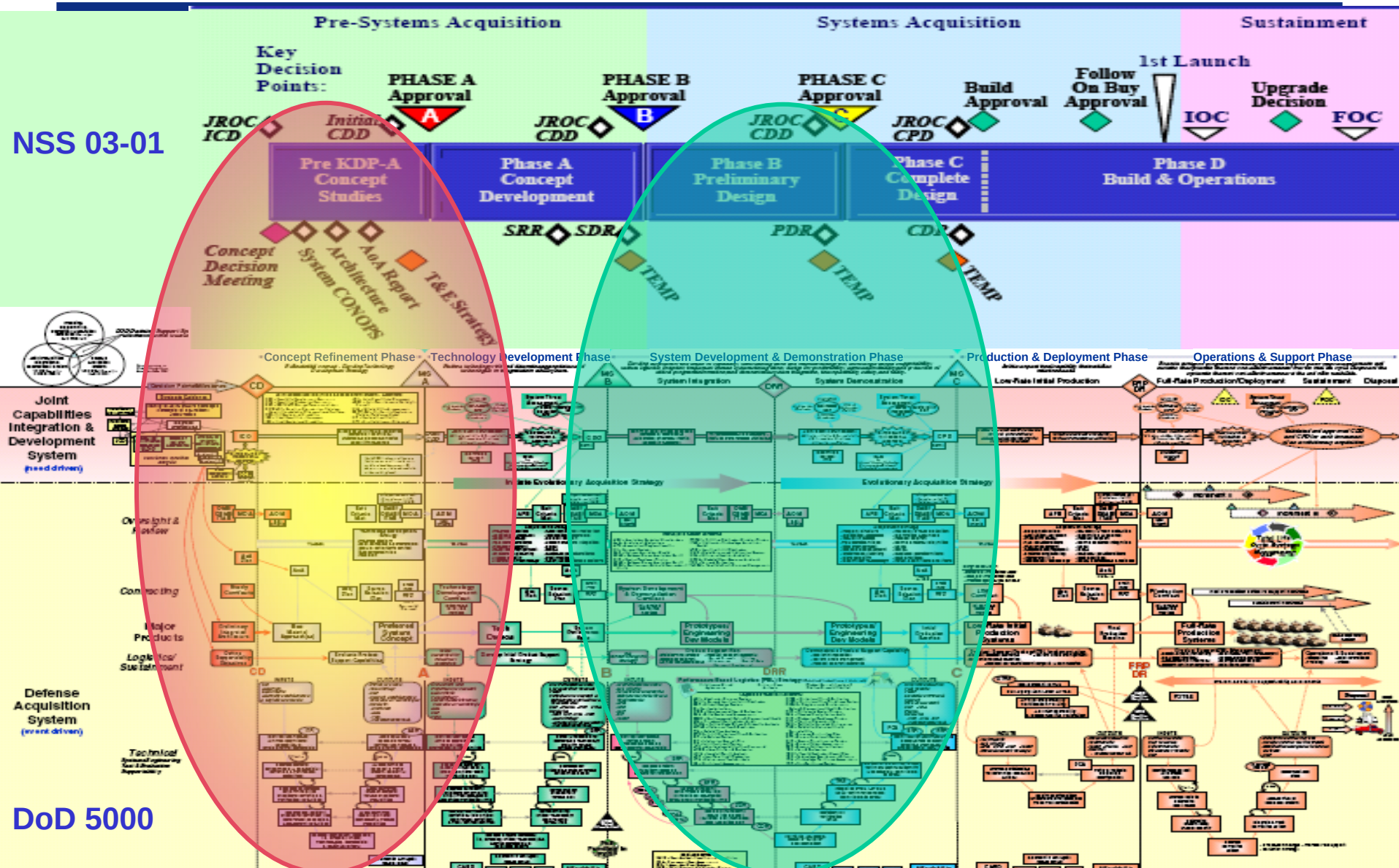
Historical Perspective



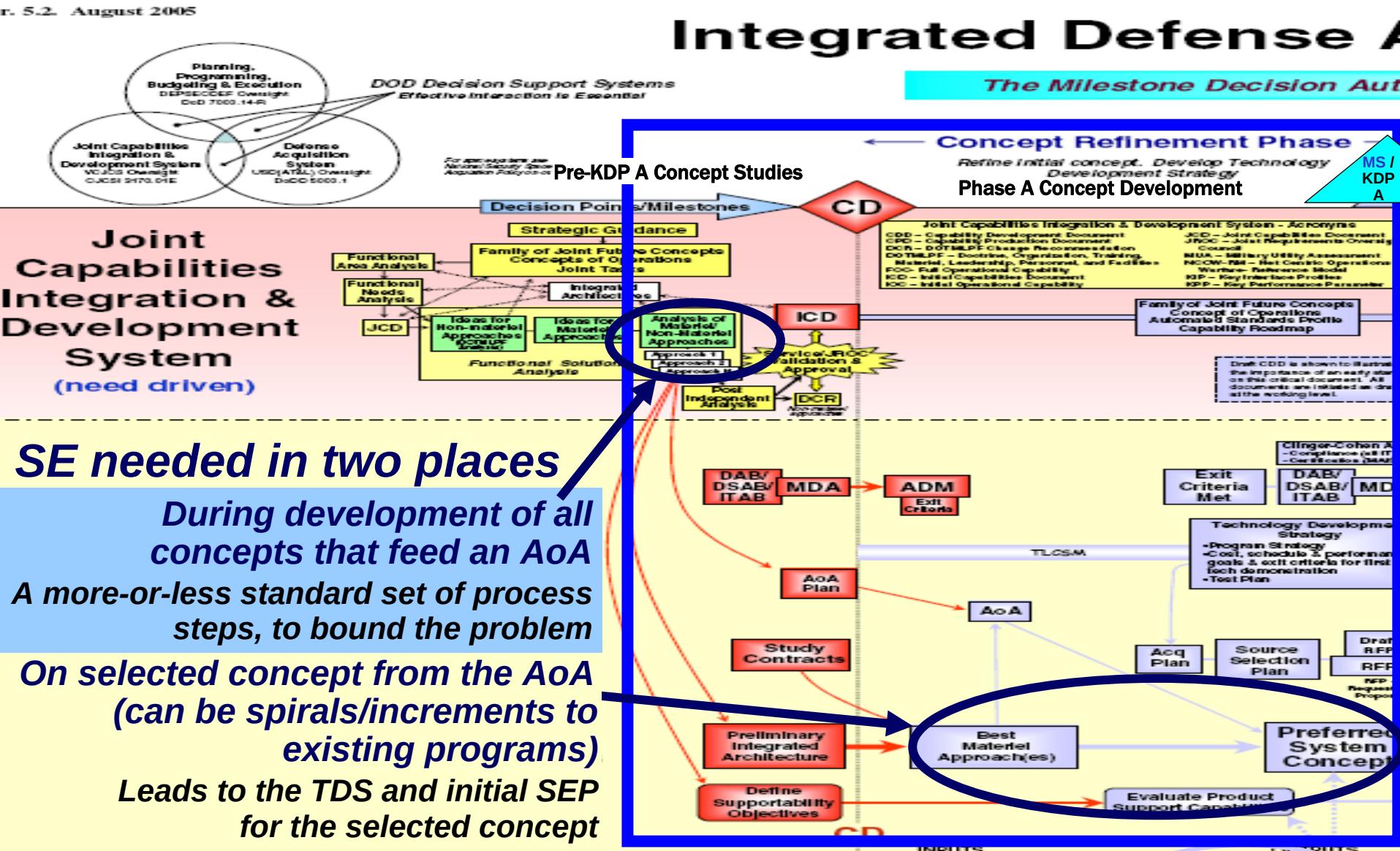
Pre-Acquisition SE ("Pre-A Systems Thinking") Overview

- **Where It's Required**
- **What It Is (and Is Not)**
- **Key Attributes**
  - **Universal**
  - **Collaborative**
  - **Not for the neophyte**
  - **Responsive but realistic**
  - **Smart choices**
- **Why It's Important**
- **The Road Ahead …**

Acquisition Life Cycles
NSS 03-01 and DoD 5000



Pre-Acquisition "Systems Thinking"
Where It's Required



SE needed in two places

During development of all concepts that feed an AoA

A more-or-less standard set of process steps, to bound the problem

On selected concept from the AoA (can be spirals/increments to existing programs)

Leads to the TDS and initial SEP for the selected concept

Pre-Acquisition "Systems Thinking"
Informing the Decision-Making Process

What it is:

- **Linkage between JCIDS and the AoA**
- **A disciplined process to:**
  - ***Scope capability needs***
  - ***Develop concepts***
  - **Do necessary *groundwork for a successful AoA***
- **Essentially a method to develop AoA entry criteria**
- **A means to identify candidate solutions and assess their TRLs**
- **Basis for Technology Development Strategy (TDS)**
  - **TDS should make up ~75% of content of SEP submitted at Milestone / Key Decision Point A for selected concept**

Pre-Acquisition "Systems Thinking"
Informing the Decision-Making Process

Alternate view:

- **"Analysis of Problem" as precursor to formal AoA**
  - **Methodology that uses SE processes to translate capability statements into families of concept designs/approaches**
    - **Trade study process**
    - **Key ground rules / constraints**
    - **Decision criteria**
    - **Methodology for populating knowledge base**
  - **Describes how operational context (architectures, military utility, etc.) drives these translations**

Pre-Acquisition "Systems Thinking"
Informing the Decision-Making Process

What it is *not*:

- **An actual requirement development effort under JCIDS**
- **An actual AoA**
- **"Gaming the system" in favor of a particular or pre-determined solution**

Attributes

- Universal
- Collaborative
- Not for the neophyte
- Responsive but realistic
- Smart choices

Universality

- **Applies to all domains, industries, product areas, research areas …**

- **One size (policy, process, procedure, prior idea …) seldom fits all**

Expanding the "V"

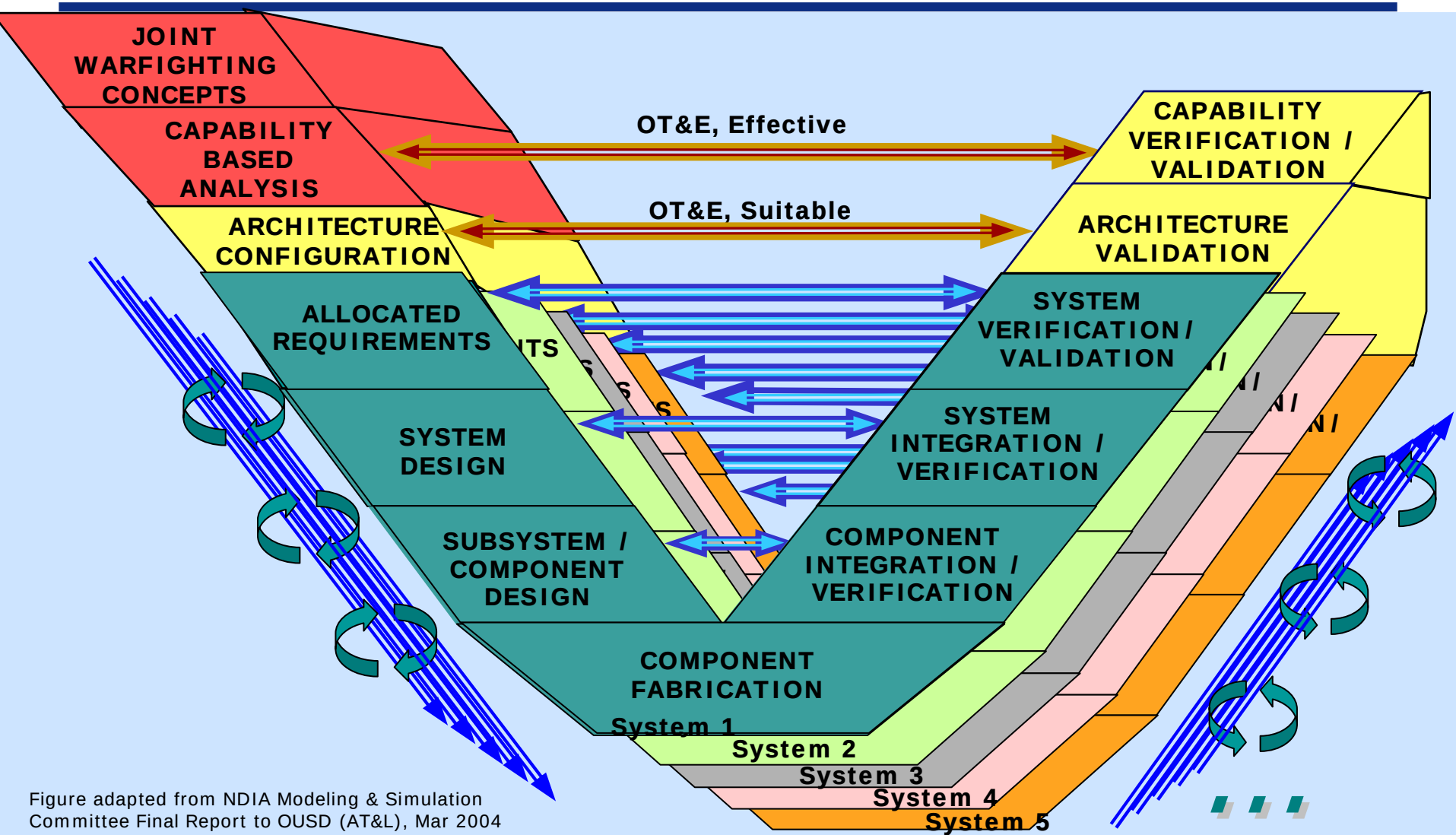


Figure adapted from NDIA Modeling & Simulation Committee Final Report to OUSD (AT&L), Mar 2004

Collaboration

- **Understand the realities of -- and constraints imposed by -- external factors and influences across government, industry, academia**

- **The human is an external factor, and always introduces uncertainties**

SE for SoS Challenges

- **Unique management and governance issues**
  - Assets acquired / operated under disparate systems and policies
  - Allocation of requirements to constituent systems
- **Integration / Verification**
  - Defining architectures to link systems and platforms
  - Resource constraints on physical testing drive extensive M&S
  - Experimentation as a development tool
  - Relatively *ad hoc* configurations in operational environment
  - Legacy system modifications / updates
    - Proprietary issues
    - Less-than-open subsystem and component designs
- **Measurement**
  - Difficult to quantify non-functional requirements
  - Mission-related quality attributes (interoperability, security, etc.) largely depend on architecture

Thinking

- **Know what you want, and measure smartly …**

  Accuracy ≠ Precision

- **Beware of becoming "DRIP"**

  Data-Rich, Information-Poor

DoD 5000 PHASE	CONCEPT DEVELOPMENT (R&D)		CONCEPT REFINEMENT / TECH DEVELOPMENT		SYSTEM DEVELOPMENT & DEMONSTRATION		PRODUCTION & DEPLOYMENT		OPERATIONS & SUPPORT	
ISO 15288 STAGE	??		??		??		??		??	
APPLICATION / INDICATOR	System	SoS/ Architecture/ Enterprise	System	SoS/ Architecture/ Enterprise	System	SoS/ Architecture/ Enterprise	System	SoS/ Architecture/ Enterprise	System	SoS/ Architecture/ Enterprise
REQUIREMENTS DEFINITION (growth, correctness/completeness)										
SYSTEM DEFINITION CHANGE RATE	0	0	1	2	3	3	3	2	1	3
REQUIREMENTS VALIDATION										
REQUIREMENTS VERIFICATION										
INTERFACE DEFINITION internal										
external										
REVIEW ACTION CLOSURES	0	1	2	2	3	2	3	2	1	1
APPROVALS internal										
external (customer)	0	1	1	1	3	3				
TECHNOLOGY MATURATION new	2	2	3	3	3	3				
old (obsolescence)					2	2				
RISK EXPOSURE	0	1	1	2	3	3	3	3	3	3
RISK HANDLING										
STAFFING / WORK EFFORT headcount										
work package completion					3	1	3	1	1	1
PROCESS COMPLIANCE	0	0	1	1	2	1	1	1	1	2
TECHNICAL MEASURES	1	1	2	2	3	3	3	3	2	3

Table entries (values are notional):
- 0 - not applicable
- 1 - low
- 2 - nominal
- 3 - high

Leading Indicators

Value by Life Cycle Phase

Candidate Metrics for the Concept Development Process

- **Distribution of concepts in the development process pipeline**
  - **Number of items in each of the various stages of a concept's lifespan**
- **Concept relevance**
  - **How well a set of concepts addresses the cost / performance / schedule trade space for a specific shortfall**
- **Baseline concept schedule**
  - **Progress of efforts to develop relevant and mature concepts to meet a shortfall**

Candidate Metrics for Development of a Concept

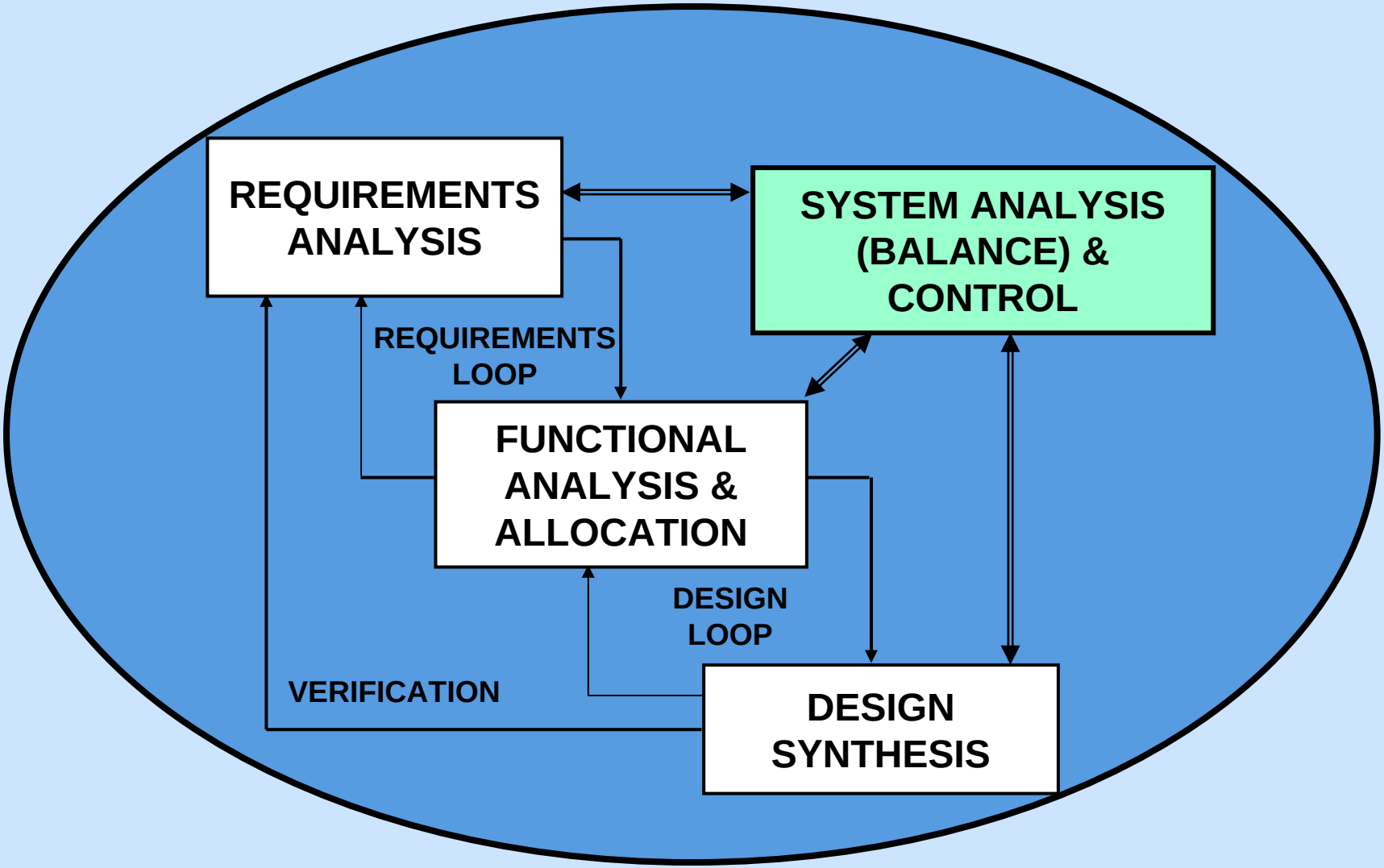
- **Supporting analyses**
  - **Cost**
  - **Risk**
  - **Military Utility**
  - **Other**
    - **Technology suitability**
    - **Producibility**
- **Technical progress**
  - **Node analysis**
  - **System- and subsystem-level trades**
  - **Key reviews**
    - **Acquisition strategy**
- **Transition opportunities**

Rational

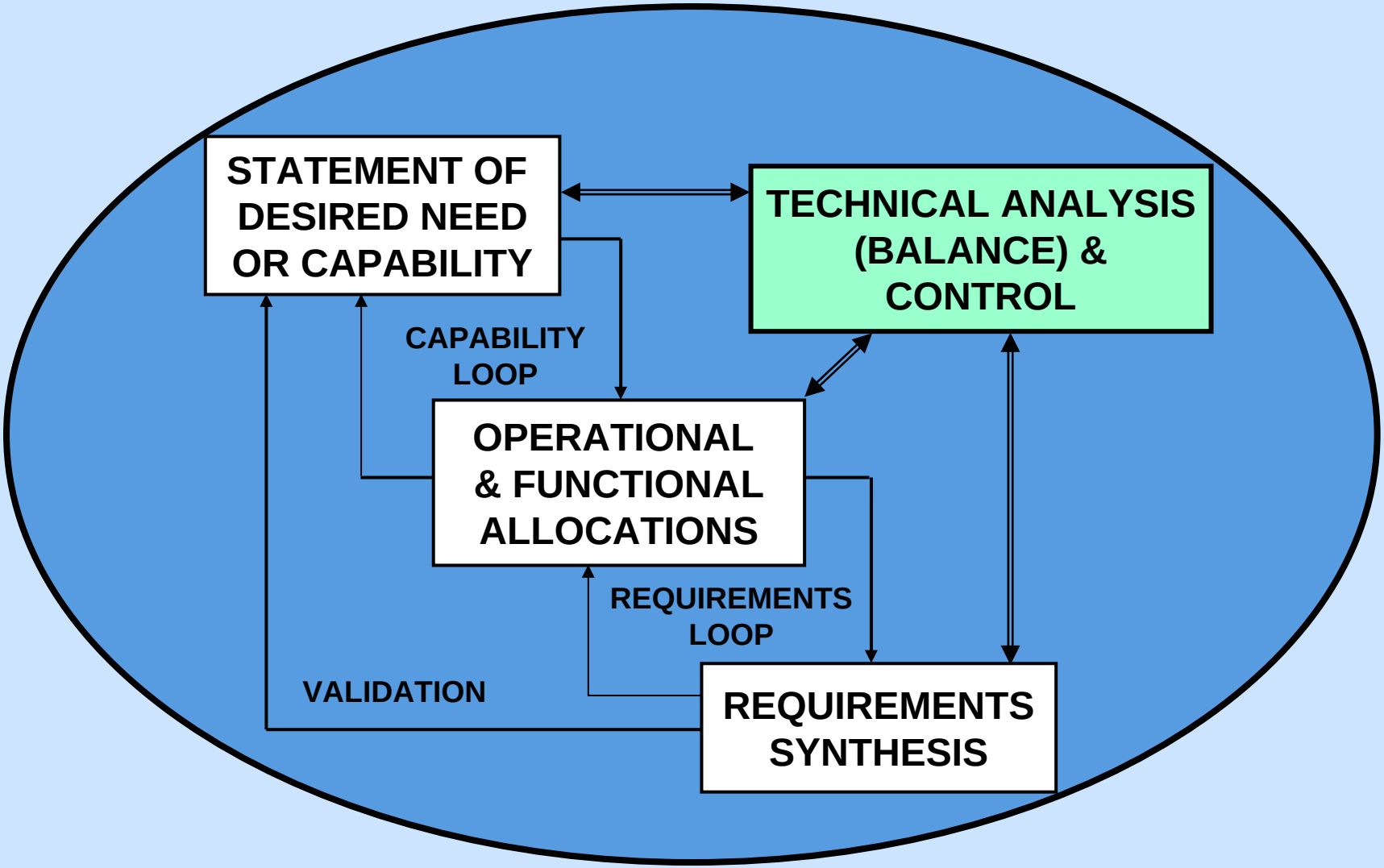
- **Customers/users often press for immediate solutions over rigorous process**

- **“Then a miracle occurs” cannot be an acquisition or transition strategy**

SE for a Product or System
Transforming Requirements to Design



"Systems Thinking" for a Capability
Transforming Needs to Requirements



Decisive

- **Decomposition and allocation must focus on HW, SW, or human first; this decision is a huge driver in defining the rest of the solution trade space**

- **Do it right, do it early; do it early, do it right: Systems Engineering follows -- but must NOT replace -- Systems Thinking**

How We Try to Fit 10 Lb. of PROGRAM Into a 5 Lb. BASELINE

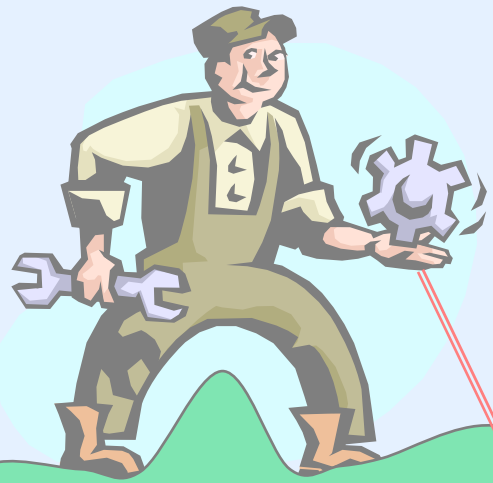
PERCEPTION

"OF COURSE WE CAN FIT THESE IN"

POLITICS

WARFIGHTER DESIRES

OTHER "NICE-TO-HAVE" ENHANCEMENTS



COMMERCIAL: PRACTICES DERIVATIVES ALTERNATIVES

WARFIGHTER NEEDS *balanced with* AVAILABLE RESOURCES = REQUIREMENTS ***BASELINE***

REQUIREMENTS CREEP / GROWTH

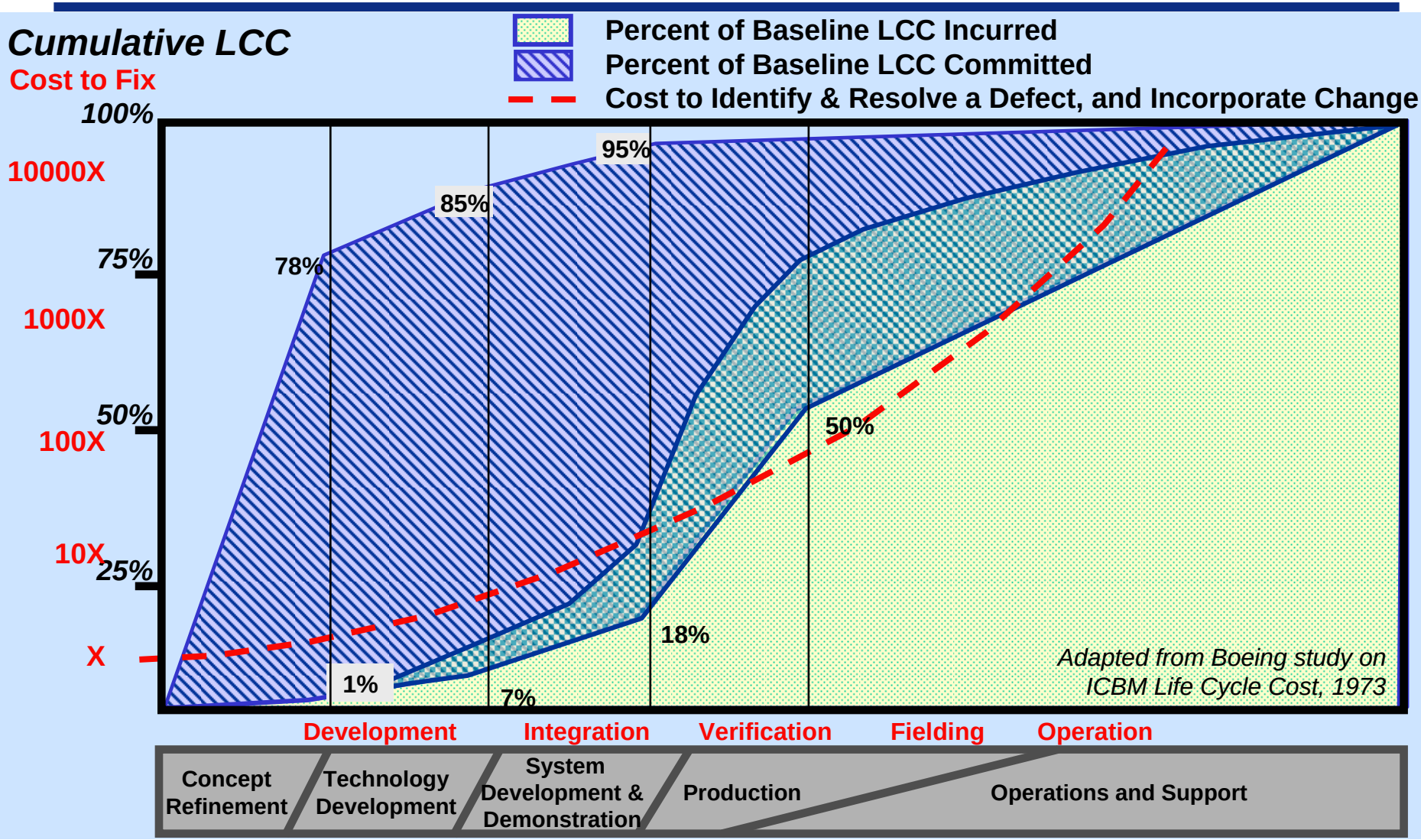
COST + SCHEDULE + PERFORMANCE = 5 LB.

REALITY

PERFORMANCE
SCHEDULE
COST

FAILED TO MEET BASELINE !

Why It's Important
Early Decisions Are Key Cost Drivers



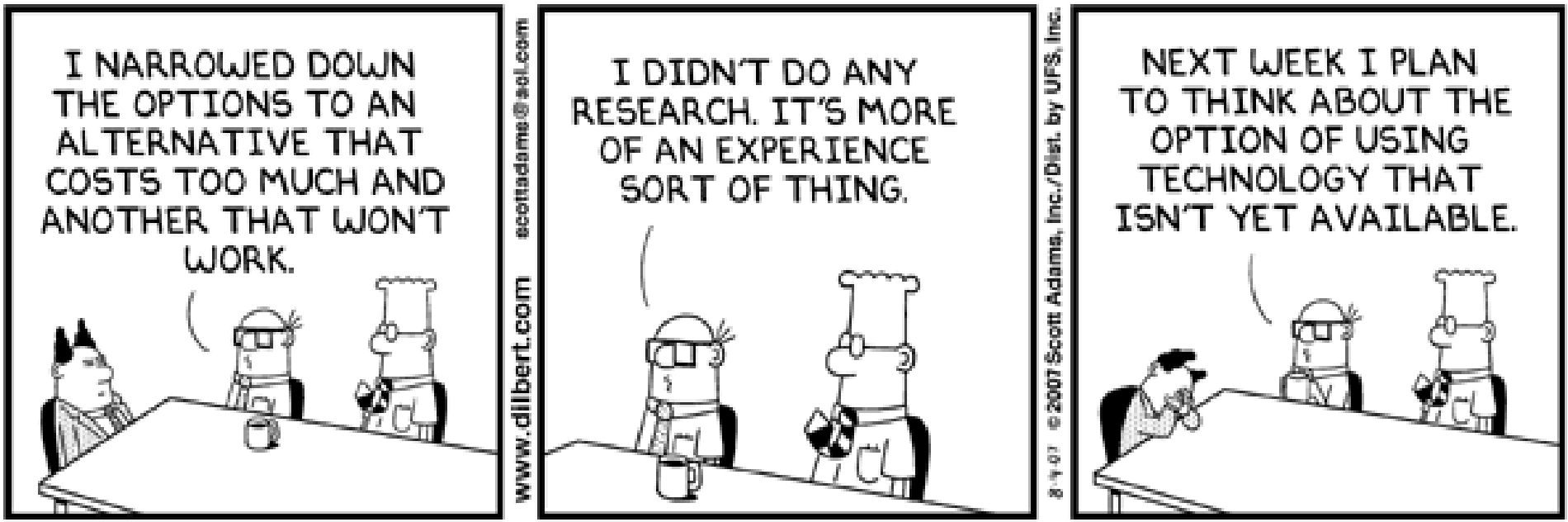
Top 10 Considerations for Applying Systems Thinking Early in the Life Cycle

- Applies to all domains, industries, product areas, research areas …
- One size (policy, process, procedure, prior idea …) seldom fits all
- Understand the realities of -- and constraints imposed by -- external factors and influences across government, industry, academia
- The human is an external factor, and always introduces uncertainties
- Know what you want and measure smartly … Accuracy ≠ Precision
- Beware of becoming "DRIP" -- Data-Rich, Information-Poor
- Customers often press for immediate solutions over rigorous process
- "Then a miracle occurs" cannot be an acquisition or transition strategy
- Decomposition and allocation can focus on either hw or sw first; this decision is a huge driver in defining the rest of the solution trade space
- Do it right, do it early; do it early, do it right: Systems Engineering must follow -- but must NOT replace -- Systems Thinking

ULTIMATE RESULTS

- Better technical planning, better integrated
- More confidence in programs entering acquisition

How NOT to do Concept Development



BACKUPS

Status of Current AF Efforts

- SMC pilot ongoing
  - Three drafts of process guide completed
  - Tailored Space Situational Awareness capability need statement; conducted exploratory trades and initial architecting
  - Currently in design phase for three concepts (one ground-based, two space-based); cost & Military Utility analyses ECD 30 Oct
  - Initial "Concept Engineering Plan" (ConEP) completed for each
- Proposing policy language to insert AF Chief Engineer review of concept pedigrees as AoA "entry criteria"
  - NOT an in-depth technical review
  - Provides avenue to weed out "back-of-the-napkin" concepts early
- ASC process guide in work; AAC & ESC pilots start CY08

FUTURE STATE

- Rigorous yet adaptable concept development processes across AF
- More robust concepts going into AoAs

Pre-Acquisition "Systems Thinking"
Boundary Conditions

Pre-Acquisition SE efforts, like those throughout the rest of the life cycle, are essentially an "integrating function"

- **Pre-A SE mainly occurs in two domains, each with set boundaries**
  - **The first domain spans the period from JCIDS initiation of a need to AoA entrance:**

$$\int_{\text{JCIDS}}^{\text{AoA Entrance}} F_1(SE)\,dSE$$

  - **The second domain continues the SE functions after the AoA until formal program handoff:**

$$\int_{\text{AoA Exit}}^{\text{Program Initiation}} F_2(SE)\,dSE$$

- **The SE functions in both domains are fundamentally similar, but there are attributes unique to each**

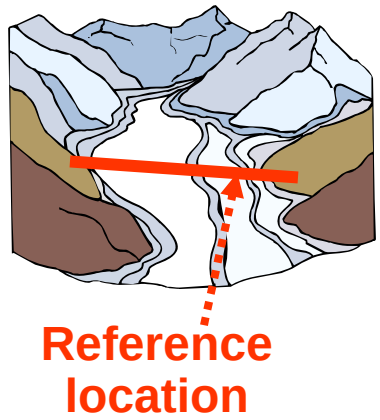
Pre-Acquisition "Systems Thinking" Example

Capability need: "Get people and equipment across a body of water"

- First pass asks key questions:
  - What does "water" mean? (Solution sets will be very different for Piscataway Creek, the Potomac River, and the Pacific Ocean.)
  - Are there any obvious constraints? (Sensitivity to water exposure? Time-in-transit limitations?)
- Initial analysis should yield various methods, and a cost / risk summary for each
  - Airlift
  - Bridge
  - Catapult (unsuitable for people)
  - Drive across (depends on depth, current, etc.)
  - Drive around (depends on total distance, thus time)
  - Ferry
  - Helicopter
  - Tunnel
- Analysts should also be able to quickly rule out candidates that don't meet constraints

Pre-Acquisition "Systems Thinking" Example

- Parametric trades within a method (bridge, tunnel, etc.) consider how relevant factors (depth, width, current, etc.) affect a baseline candidate solution
  - "A mile upstream the channel is narrower. The shorter span means ~30% less material cost, but road access and construction staging are difficult."
  - "A mile downstream the current is slower. The longer span means ~20% more material cost, but you can complete construction earlier."



- Once the AoA looks at families of candidates and concludes that a bridge is the best solution, a similar process is employed to determine the optimum type (cantilever, suspension, pontoon, single- or two-span draw, etc.)
- Pre-AoA measures are high-level programmatic / operational parameters (cost, schedule, vehicle capacity, etc.)
- Post-AoA measures have a more traditional design and execution focus (EVM, weight, material durability, etc.)

Focus Areas for SE Planning
Based on OSD SEP Preparation Guide

- **Program Requirements**
  - Capabilities, CONOPS, KPPs
  - Statutory/regulatory
  - Specified/derived performance
  - Certifications
  - Design considerations
- **Technical Staffing/Organization**
  - Technical authority
  - Chief/Lead Systems Engineer
  - IPT coordination
  - IPT organization
  - Organizational depth
- **Systems Engineering Process**
  - Technical processes
  - Technical management processes
  - Process improvements
  - Key tools and resources
  - Trade studies
  - Linkage to contractor SE effort
- **Technical Baseline Management**
  - Responsibilities
  - Definition of baselines
  - Requirements traceability
  - Specification tree and WBS link
  - Technology maturity and risk
- **Technical Review Planning**
  - Event-driven reviews
  - Management of reviews
  - Technical authority chair
  - Key stakeholder participation
  - Peer participation
- **Integration with Overall Management of the Program**
  - Linkage with other program plans
  - Program manager's role in tech. reviews
  - Risk management integration
  - Test and logistics integration
  - Contracting considerations

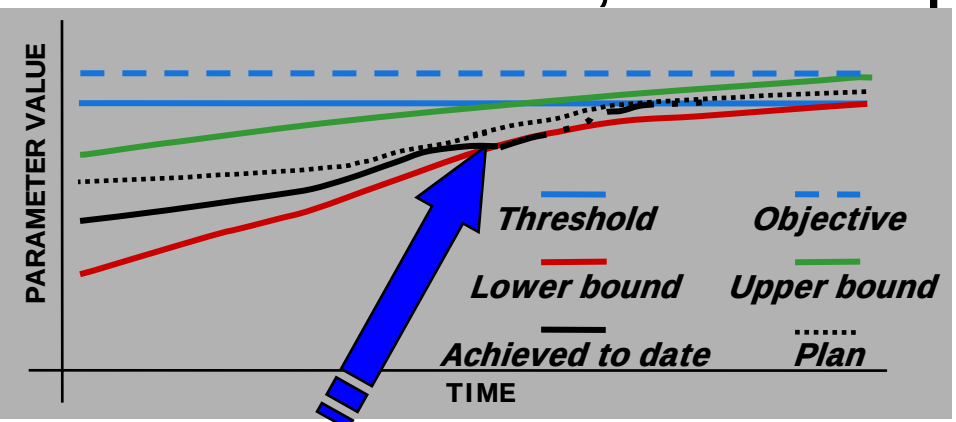
Highlight – greatest applicability to Pre-A efforts

Top Considerations for Applying Early SE to SoS

- An end product that is usable as an individual entity (e.g., by s/n) is generally at the top level of the system architecture. An end product or capability that incorporates or requires multiple entities, many or all of which have human interfaces, is more of an SoS.
- The whole is not necessarily equal to the sum of the parts. What distinguishes a system of systems from a discrete system is that the behavior of the whole cannot be predicted from the aggregate of the constituent elements or subsystems. The existence of multiple human interactions / interfaces is a huge part of this.
- Integration and verification plans and resources must be in place early. This includes models and simulations, experimentation venues, and integration labs, as well as the physical assets to be tested. However, when analyzing test data, it is essential to remember that if enough is good, more is not necessarily better.

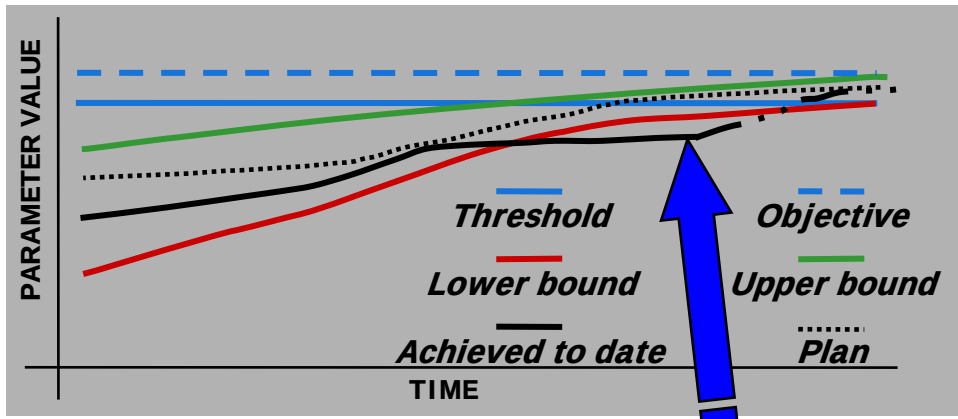
Focus Areas for Technical Execution

- Representative parameters related to Technical Performance Measures (TPM)
  - Hardware – weight, speed, power, cooling, cross-section, bandwidth
  - Software – throughput, lines of code
  - Verification – test asset deliveries, test points completed with valid data
  - Logistics – reliability, maintainability
- Integration – physical and information interface definitions; verification plans
- Earned Value Management System (EVMS) data
  - Cost variances
  - Schedule variances
- Program execution
  - Staffing
  - Subcontracting
  - Specification approvals
  - Closure of review actions



Monitor trend; take action here

Plan is probably achievable



Not here

Overly optimistic "get-well" plan

Emerging Focus Areas

- **Technical**
  - SE for SoS / Architecting
  - Manufacturing Readiness
  - Human Systems Integration
  - Specifications and Standards
- **Governance & Oversight**
  - MDA Certification
  - System & Software Assurance (Security & Program Protection)
- **Multi-Faceted**
  - Enterprise-level SE
  - Industrial Base

SE Perspectives

Acquisition, Operations, Integration, Architecture