Headquarters U.S. Air Force

I n t e g r i t y - S e r v i c e - E x c e l l e n c e

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

Measuring Systems Thinking & Technical Planning for Air Force Systems

Practical Software & Systems Measurement
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Phases	Capability Planning	CD	Concept Refinement	A	Technology Development	B	System Development & Demonstration	C	Production & Deployment, Operations & Support, Disposal
Milestones / KDPs									

1. Algorithms
2. Integration
3. Net-Ready Data Link
4. Lethality
5. Airframe

LIKELIHOOD
CONSEQUENCE

- **Consistent application of rigorous life cycle SE in all AF product lines, enabled by a skilled workforce and a policy framework with an integrated life cycle perspective**
- **Delivery and support of quality systems/SoS/software, on cost and on schedule**

- **Pre-Acquisition SE ("Pre-A Systems Thinking")**
  (Prior to formal program initiation --
  Milestone / Key Decision Point A or B)
  - **Where It's Required**
  - **What It Is (and Is Not)**
  - **Why It's Important**

- **SE for Systems of Systems (SoS)**
  - **Characteristics**
  - **Challenges**
  - **Considerations**

- **Focus Areas for Planning and Measuring**

- **The Road Ahead …**

Acquisition Life Cycles
NSS 03-01 and DoD 5000
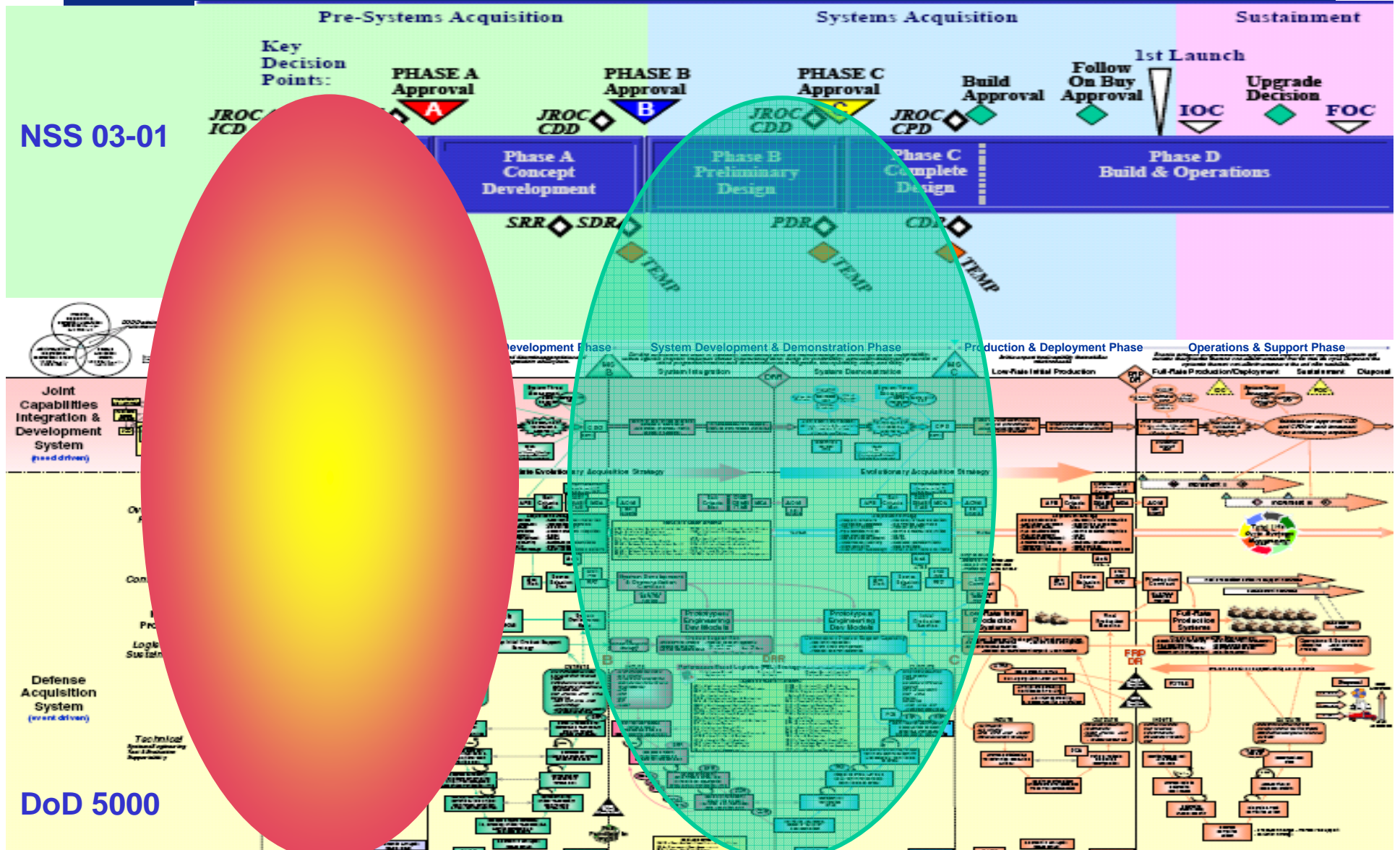
Pre-Acquisition "Systems Thinking"
Boundary Conditions

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 SE domain spans the period from JCIDS initiation of a need to AoA entrance:**

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

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

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

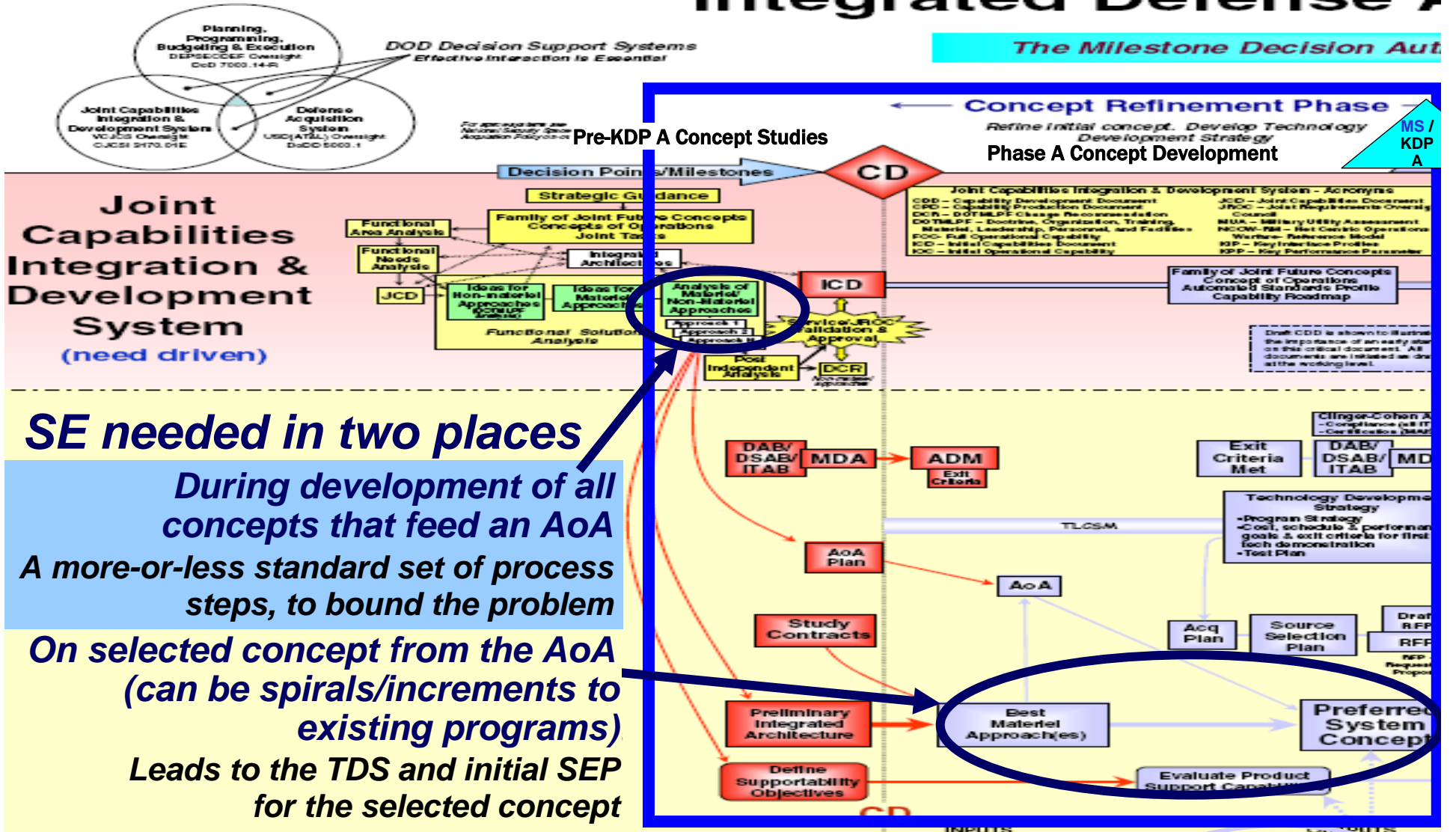- **The SE functions in both domains are fundamentally similar, but there are attributes unique to each**

Pre-Acquisition "Systems Thinking"
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:**
  - **The tie between JCIDS and the AoA**
  - **A disciplined process to scope capability needs, *develop concepts,* and do necessary *groundwork for a successful AoA***
  - **Essentially a method to develop AoA entry criteria**
- **What it is (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 also is:**
  - **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**

- **What it is *not*:**
  - **An actual requirement development effort under JCIDS**
  - **An actual AoA**
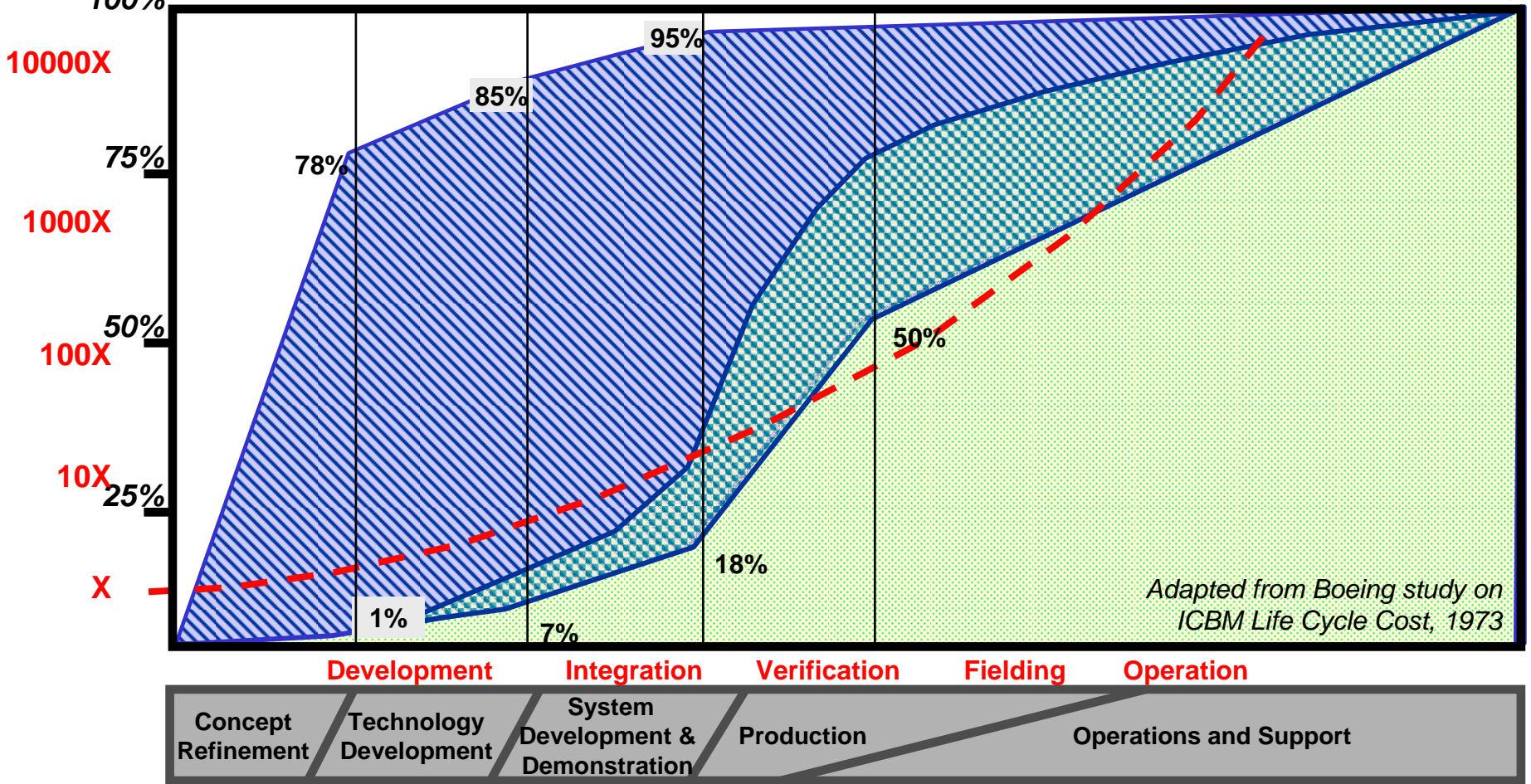 - **"Gaming the system" to favor a solution**

Why It's Important
Early Decisions Are Key Cost Drivers

Cumulative LCC
Cost to Fix

Legend:
- Percent of Baseline LCC Incurred
- Percent of Baseline LCC Committed
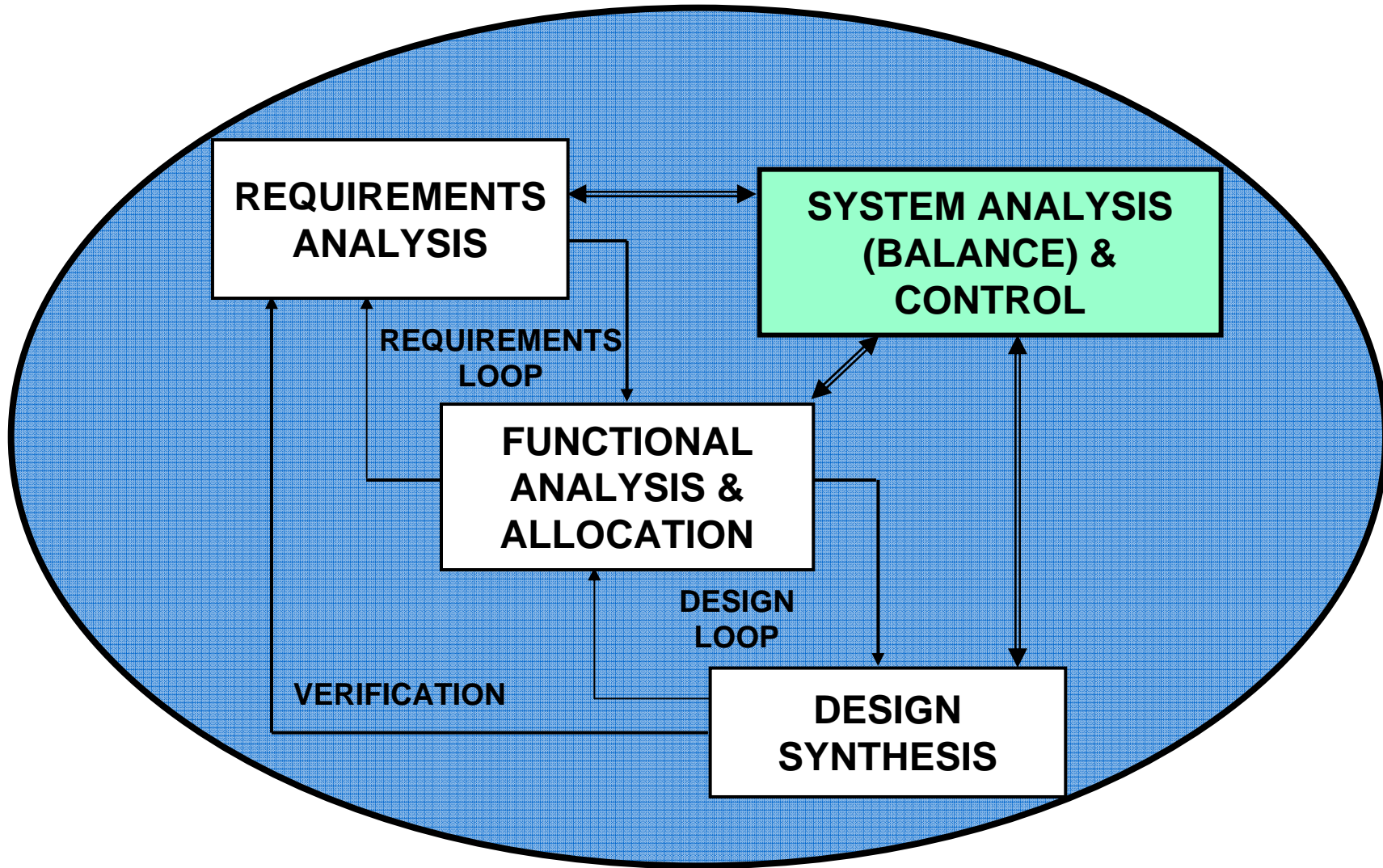- Cost to Identify & Resolve a Defect, and Incorporate Change

Vertical axis (left, black): 100%, 75%, 50%, 25%
Vertical axis (left, red): 10000X, 1000X, 100X, 10X, X

Chart values: 78%, 85%, 95%, 50%, 18%, 1%, 7%

Adapted from Boeing study on ICBM Life Cycle Cost, 1973

Phase labels (red): Development, Integration, Verification, Fielding, Operation

Phase boxes: Concept Refinement, Technology Development, System Development & Demonstration, Production, Operations and Support

Integrity - Service - Excellence

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SE for a Product or System
Transforming Requirements to Design

REQUIREMENTS ANALYSIS

SYSTEM ANALYSIS (BALANCE) & CONTROL

REQUIREMENTS LOOP

FUNCTIONAL ANALYSIS & ALLOCATION

DESIGN LOOP

VERIFICATION

DESIGN SYNTHESIS

STATEMENT OF DESIRED NEED OR CAPABILITY

TECHNICAL ANALYSIS (BALANCE) & CONTROL

CAPABILITY LOOP

OPERATIONAL & FUNCTIONAL ALLOCATIONS

REQUIREMENTS LOOP

VALIDATION

REQUIREMENTS SYNTHESIS
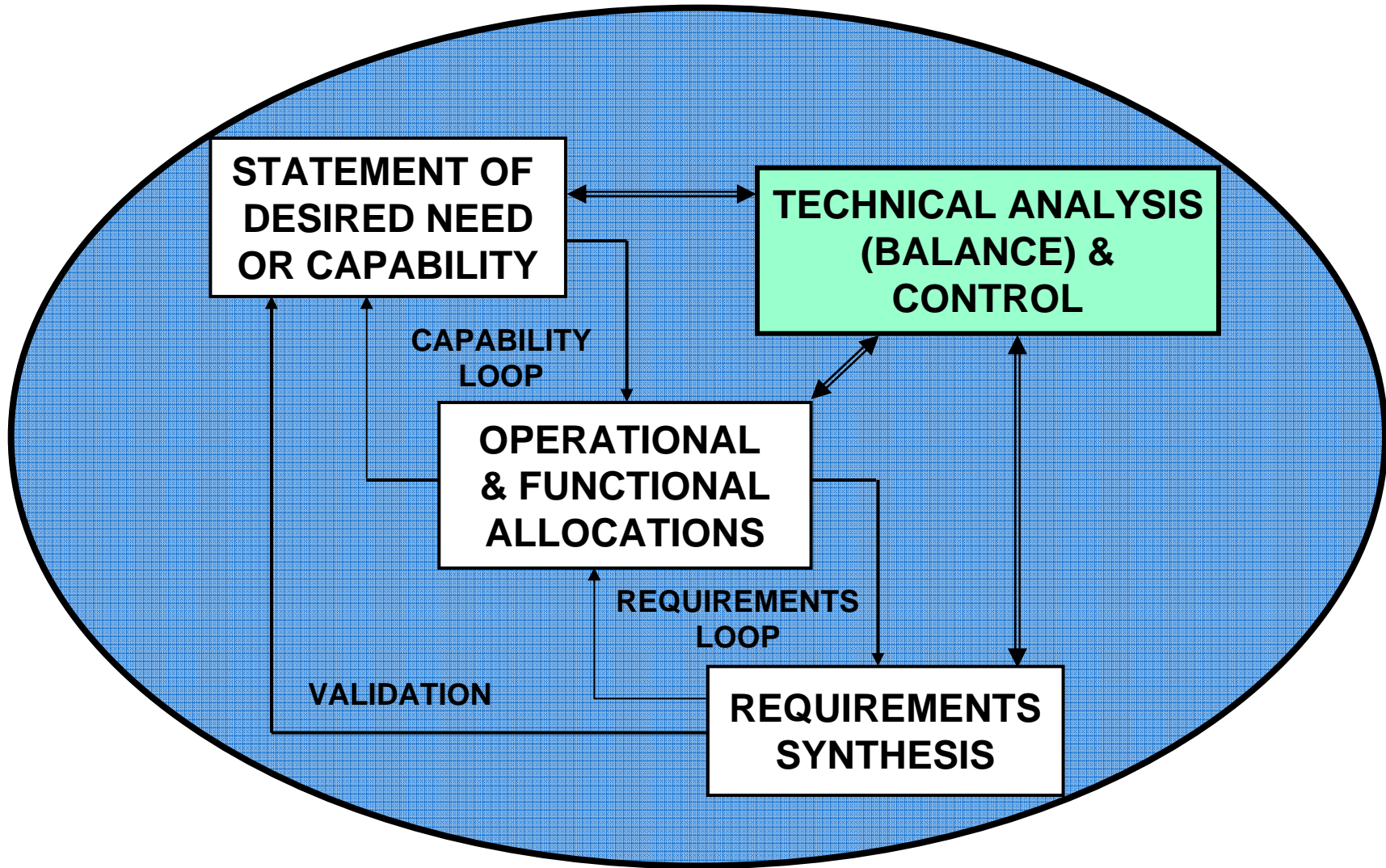
Pre-Acquisition "Systems Thinking" *Example*

**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."**

Reference location

- **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.)**
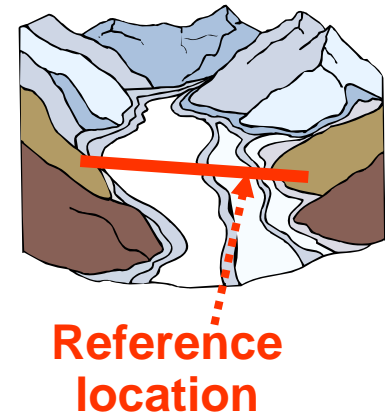
Focus Areas for SE Planning
Based on OSD SEP Preparation Guide

- **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*

Focus Areas for Measuring Progress

- **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**
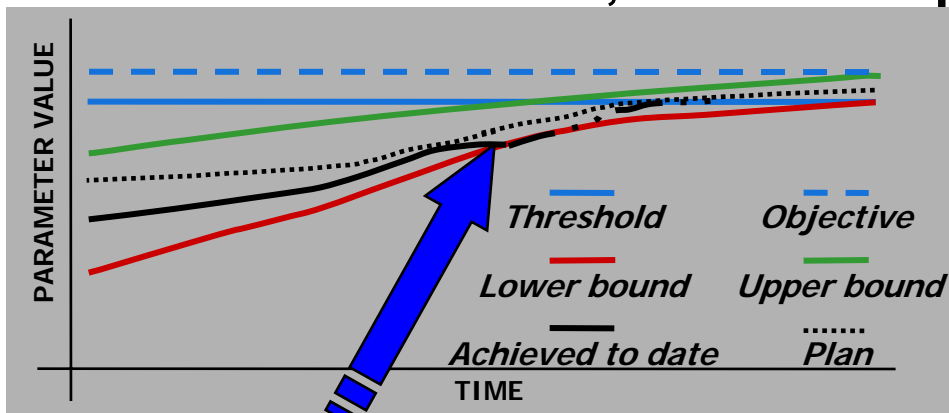
Monitor trend; take action here
Plan is probably achievable
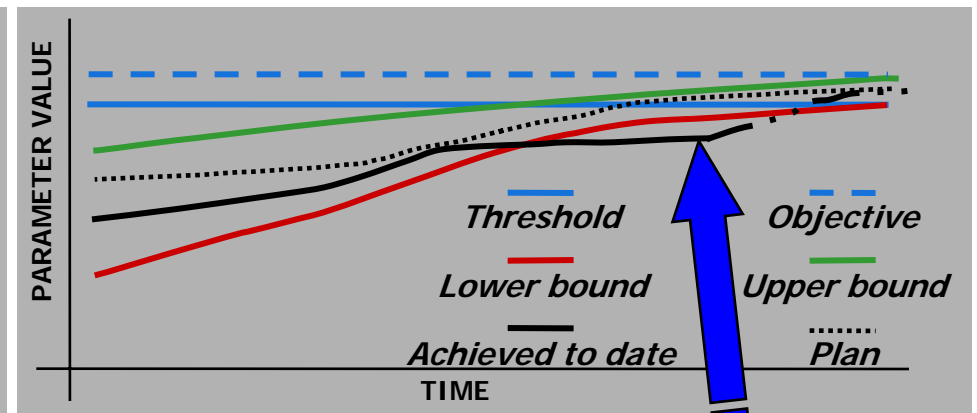
Not here
Overly optimistic "get-well" plan

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**

- **Fundamental processes (both technical and technical management) are largely the same as for "classical" SE**

- **Greater need for up-front emphasis to address architecture and interfaces**

- **Relatively *ad hoc* configurations in operational environments: multiple hardware, software, and human interfaces**

- **Experimentation as a development tool**

- **Unique management and governance issues**
  - **Assets acquired / operated under disparate systems and policies**
- **Integration / Verification**
  - **Defining architectures to link systems and platforms**
  - **Resource constraints on physical testing drive extensive M&S**
  - **Legacy system modifications / updates**
    - **Proprietary issues**
    - **Less-than-open subsystem and component designs**
- **Measurement**
  - **Allocation of requirements to constituent systems**
  - **Difficult to quantify non-functional requirements**
  - **Mission-related quality attributes largely depend on the architecture**
    - **Interoperability**
    - **Security**
    - **etc.**

Top 3 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.

SE: SoS/Architecture Perspective

JOINT WARFIGHTING CONCEPTS

CAPABILITY BASED ANALYSIS

OT&E, Effective

CAPABILITY VERIFICATION / VALIDATION

ARCHITECTURE CONFIGURATION

OT&E, Suitable

ARCHITECTURE VALIDATION

ALLOCATED REQUIREMENTS

INTEGRATED VERIFICATION/ VALIDATION

CONSTITUENT SYSTEM

CONSTITUENT SYSTEM

TASKINGS / RQMTS

INTEG. & VERIF.

CONSTITUENT SYSTEM OPS

System 1 - AEA
System 2 - PGM
System 3 - SIGINT
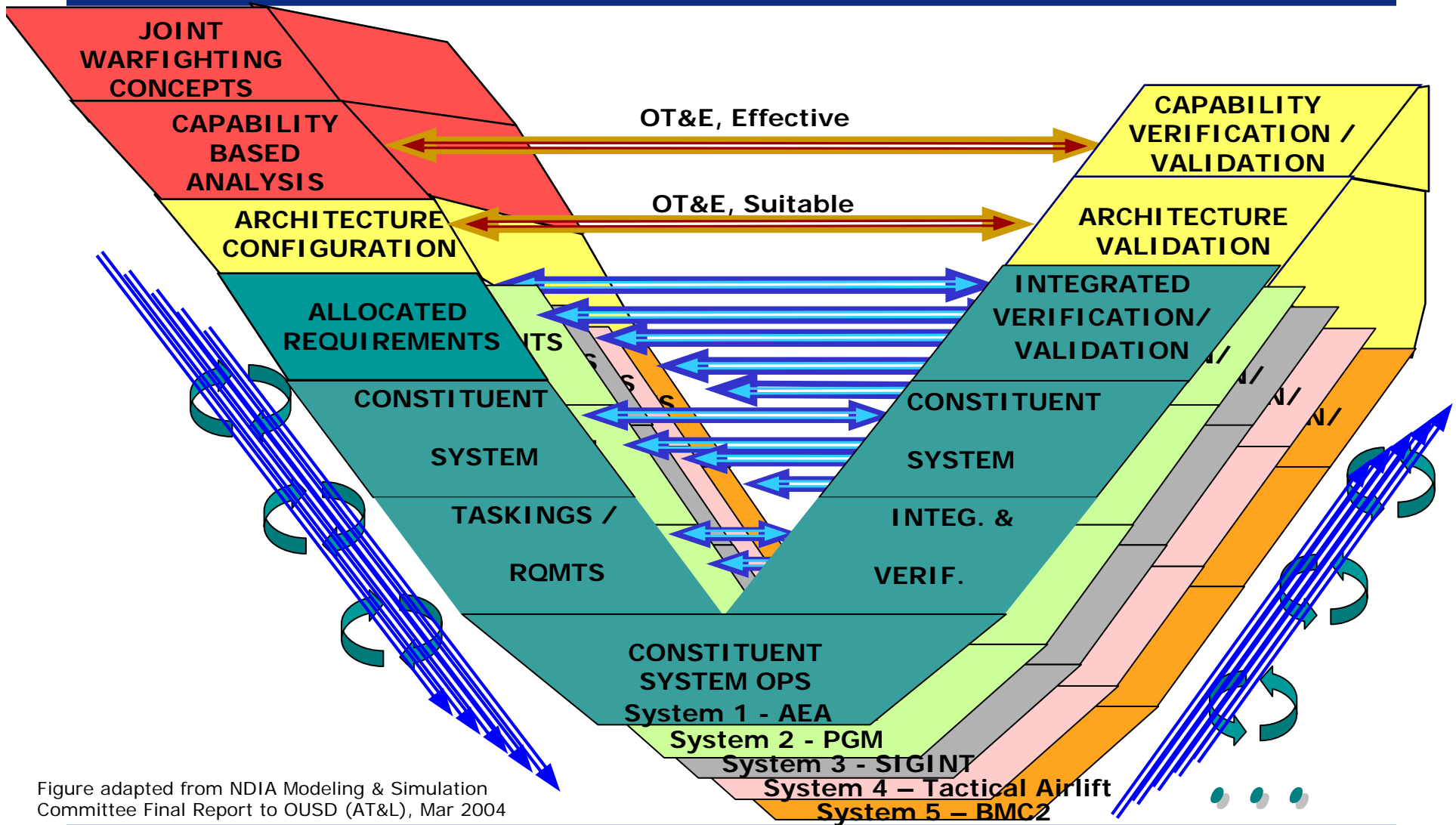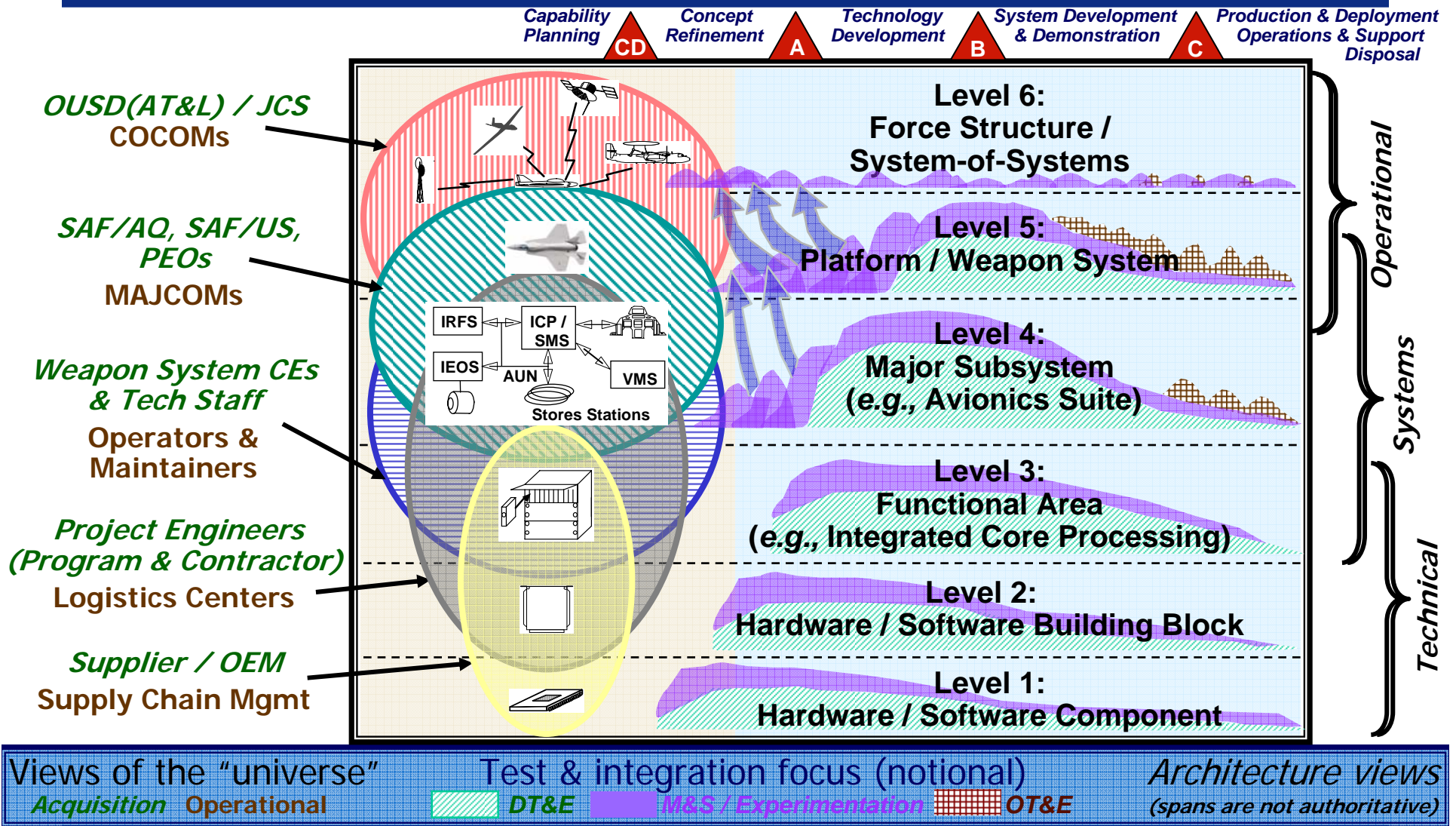System 4 – Tactical Airlift
System 5 – BMC2

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

SE Perspectives
Acquisition, Operations, Integration, Architecture

| Capability Planning | CD | Concept Refinement | A | Technology Development | B | System Development & Demonstration | C | Production & Deployment Operations & Support Disposal |

OUSD(AT&L) / JCS
COCOMs

SAF/AQ, SAF/US, PEOs
MAJCOMs

Weapon System CEs & Tech Staff
Operators & Maintainers

Project Engineers (Program & Contractor)
Logistics Centers

Supplier / OEM
Supply Chain Mgmt

Level 6:
Force Structure / System-of-Systems

Level 5:
Platform / Weapon System

Level 4:
Major Subsystem (e.g., Avionics Suite)

Level 3:
Functional Area (e.g., Integrated Core Processing)

Level 2:
Hardware / Software Building Block

Level 1:
Hardware / Software Component

IRFS → ICP / SMS
IEOS
AUN — VMS
Stores Stations

Operational
Systems
Technical

Views of the "universe" — Test & integration focus (notional) — *Architecture views*
Acquisition Operational — DT&E — *M&S / Experimentation* — OT&E — *(spans are not authoritative)*

Integrity - Service - Excellence

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Top 10 Considerations for Applying SE Early in the Life Cycle

- Applies to all domains, industries, product areas, research areas
- Applies to technical efforts across government, industry, academia
- HOWEVER one size (policy, process, procedure) does not fit all
- Understand the realities of -- and constraints imposed by -- external factors and influences
- The human is an external factor, and always introduces uncertainties
- 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
- "Then a miracle occurs" is not an acquisition or transition strategy
- Beware of "DRIP" -- Data-Rich, Information-Poor
- Measure smart … accuracy isn't the same as precision
- **Systems Engineering must follow -- but must NOT replace -- Systems Thinking**

ULTIMATE RESULTS

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

"We demand rigidly defined areas of doubt and uncertainty!"

Douglas Adams,
The Hitchhiker's Guide to the Galaxy