

***Systems Engineering***  
***versus***  
***Nonlinearity, Complexity***  
***and Adaptation***



**Naval Postgraduate School**

**November 17, 2005**

**Otto Jons**

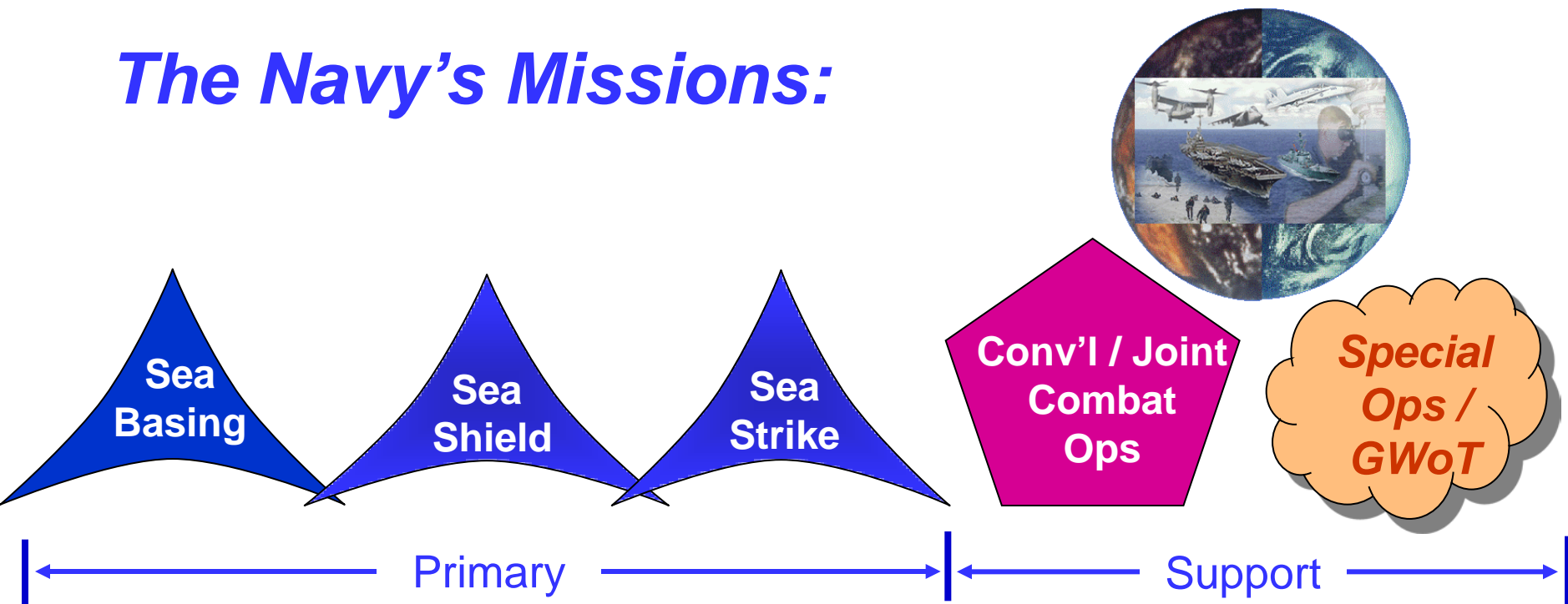


**EXPERIENCE. RESULTS.**



- ***Naval Missions & Systems***
  - ***Transportation Systems***
  - ***Warfare & Warfare Systems***
- ***System Dynamics & Complexity***
  - ***Dynamic Feedback / Complex Adaptive Systems***
  - ***The Limits of (Traditional) Engineering***
- ***DOD Systems Development & Acquisition***
  - ***A Critical Evaluation***
- ***Some Solutions***

## The Navy's Missions:



**Prerequisites:** - *RDT&E of Naval Systems*

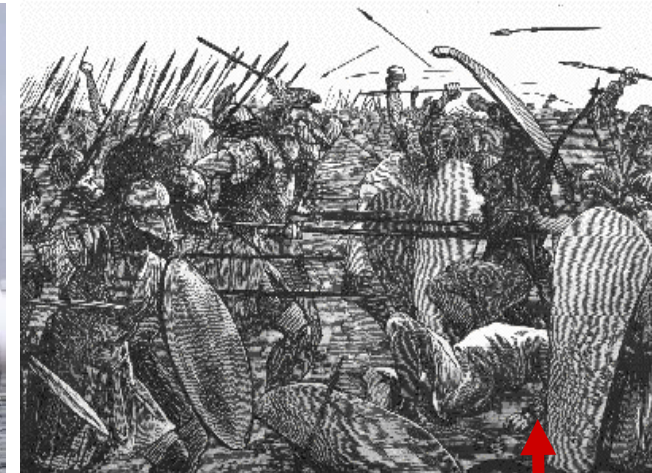
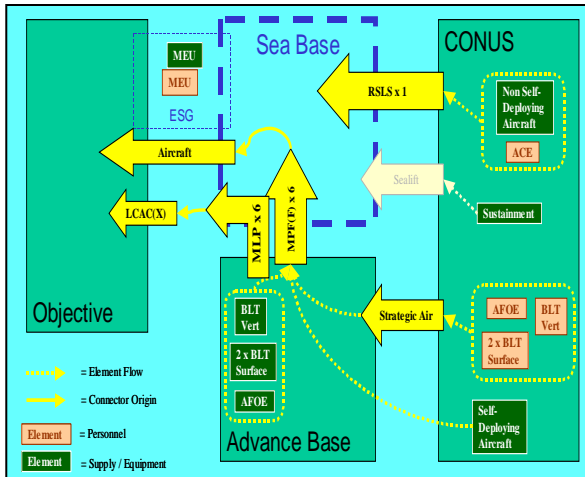
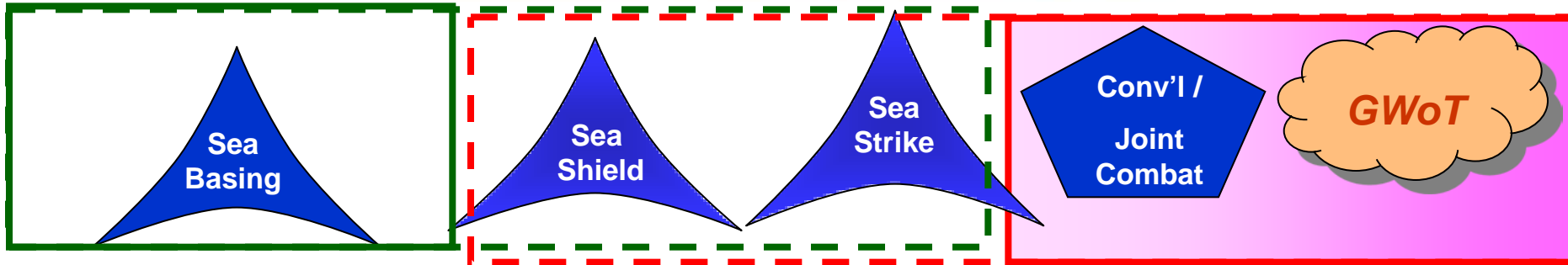
→ **A Closer Look at Naval Systems**

**= The "Means" to Accomplish the Missions**

# Naval Systems: A Closer Look



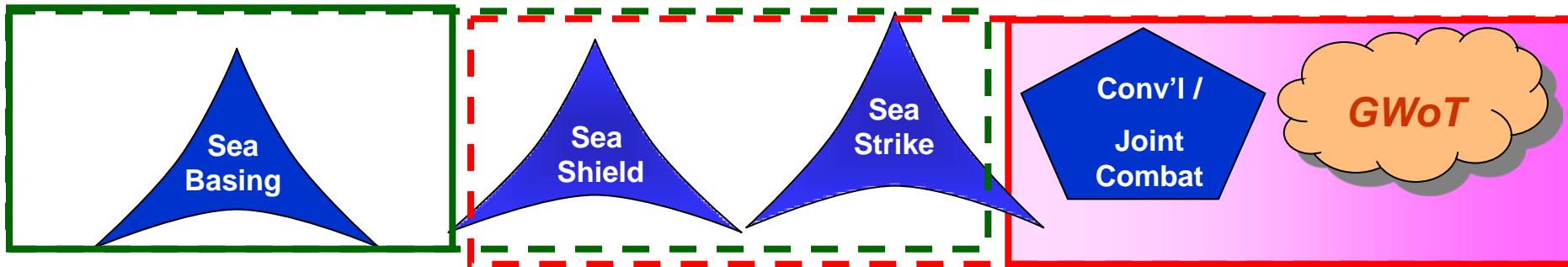
EXPERIENCE. RESULTS.



**Hybrid Systems**  
**Transportation Systems**

**Warfare Systems**

**Engineering Systems**  
 Engineering Systems  
 Engineering Systems



## Transportation System

- Measure of Effectiveness: Throughput

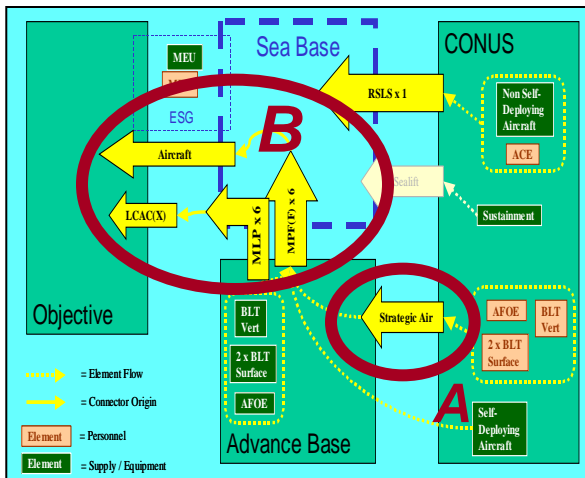
$$= \text{Payload (P)} \times \text{Distance (D)} / \text{Time (T)}$$

where  $T = \text{Time-to-Load} + \text{Time-to-Unload}$   
 $+ \text{Time-to-Transit} (= D/V)$

- (A) – Shuttle Ship:

$$E = P \times D / (T_{Ld} + D / V + T_u)$$

- (B) – Transportation Chain/ Network:  
Requires Integration over All Links



**Still: Family of Traditional Engineering Systems (TES)**



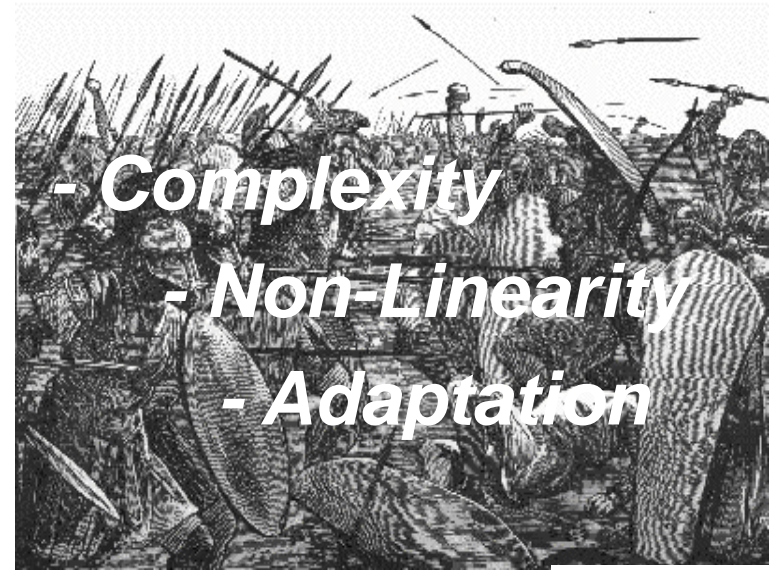
## Measure of Effectiveness:

# Winning

## Effectiveness Parameters:

- Troops & Systems (“Means”)
- Strategies, Tactics, CONOPS (“Ways”)
- The Environment
- The Human Dimension (“Will”; per Clausewitz)

- Both “Ours and “Theirs” -

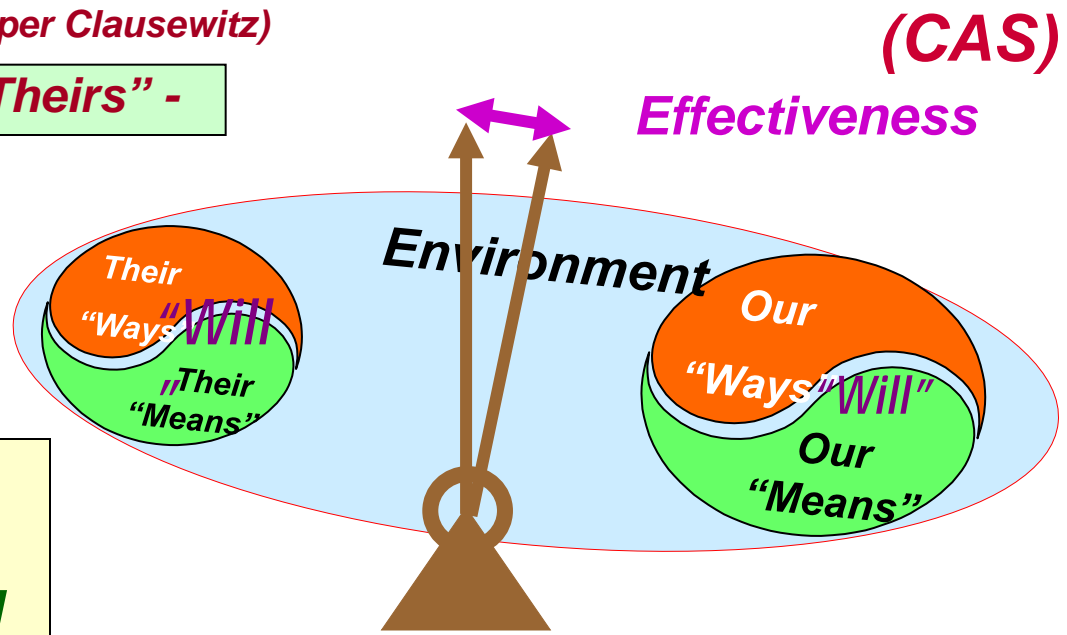


(CAS)

## Fundamental Strategy:

Superior Strength  
@ the Point-of-Contact

Combat....  
....Chess....  
...or Football



Effectiveness

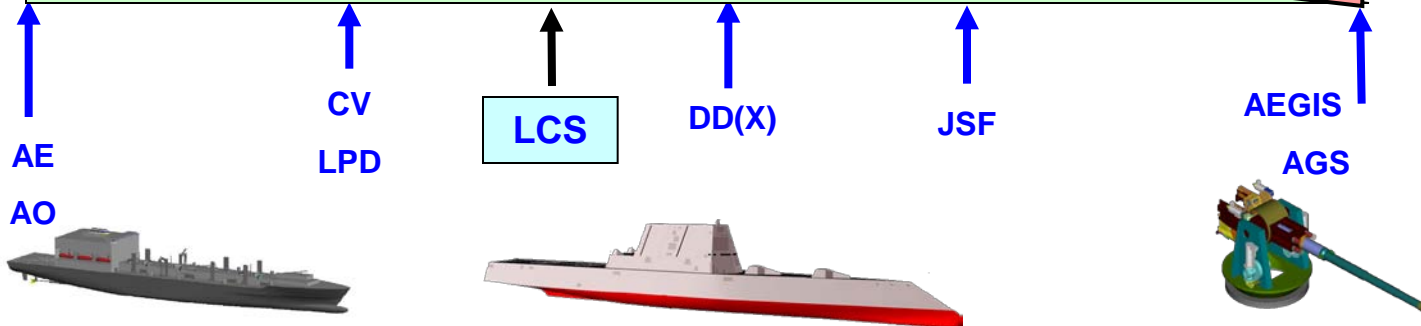
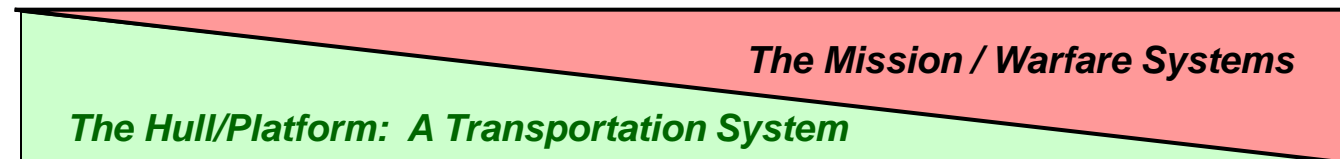
## Naval Ship Systems

*The Weapon Suit: (Part of )  
a Warfare System*



*The Hull: A Transportation System*

**The Warship:  
Both**



**Decoupling: 30+ Years of Missed Opportunities**



- ***Naval Missions & Systems***

- ***Transportation Systems***

- ***Warfare & Warfare Systems***



- ***System Dynamics & Complexity***

- ***Dynamic Feedback / Complex Adaptive Systems***

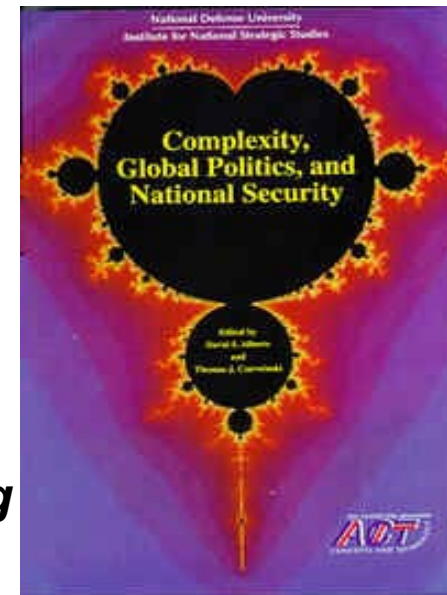
- ***The Limits of (Traditional) Engineering***

- ***DOD Systems Development & Acquisition***

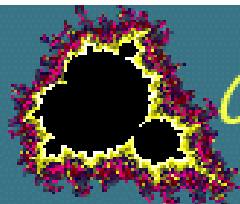
- ***A Critical Evaluation***

- ***Some Solutions***

- 1950's – Jay Forrester: Father of System Dynamics; published his book titled *“Industrial Dynamics”* in 1961
- 1960's – Edward Lorenz: Long-range weather forecast modeling; Benoit Mandelbrot: *“The Fractal Geometry of Nature”*
- 1980s - Santa Fe Institute: Complex Adaptive Systems. James Gleick's best-seller *“Chaos: Making a New Science”*.
- 1992 - Waldrop *“Complexity: The Emerging Science at the Edge of Order and Chaos”*, Lewin: *Complexity: “Life at the Edge of Chaos”*.
- 1992 – A. Beyerchen, *“Clausewitz, Nonlinearity, and the Unpredictability of War”*; Steven Mann: *“Chaos Theory and Strategic Thought”*
- 1996 - U.S. Marine Corps, *MCDP 6-Command and Control*, applying Complexity Theory concepts.
- 1996 - NDU Symposium *“Complexity, Global Politics, and National Security”* (NDU and RAND)
- 2000 – J. Sterman: *“Business Dynamics: Systems Thinking and Modeling in a Complex World”*



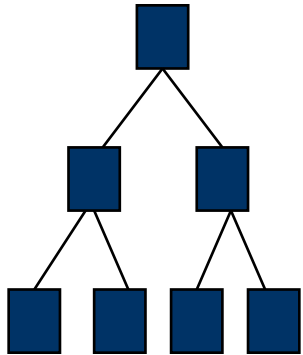
- *The Simple and the Complex*  
(*Murray Gell-Mann*)
- *America in the World Today*  
(*Zbigniew Brzezinski*)
- *Complex Systems: The Role of Interactions* (*Robert Jervis*)
- *Many Damn Things Simultaneously: Complexity Theory and World Affairs* (*James N. Rosenau*)
- *Complexity, Chaos and National Security Policy: Metaphors or Tools?* (*Alvin M. Saperstein*)
- *The Reaction to Chaos*  
(*Steven R. Mann*)
- *Clausewitz, Nonlinearity, and the Importance of Metaphor*  
(*Alan D. Beyerchen*)
- *Complexity and Organization Management*  
(*Robert R. Maxfield*)
- *Command and (Out of) Control: The Military Implications of Complexity Theory*  
(*John F. Schmitt*)
- *Complexity Theory and Air Power* (*Steven M. Rinaldi*)
- *Chaos Theory and U.S. Military Strategy: A "Leapfrog" Strategy for U.S. Defense Policy*  
(*Michael J. Mazarr*)



*Complexity, Global Politics, and National Security*

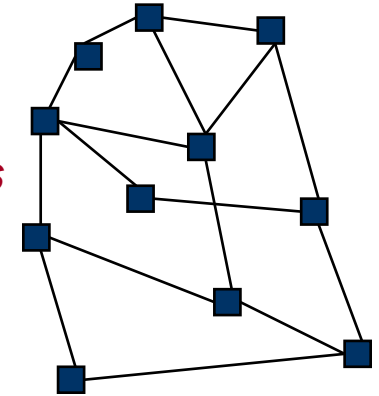
# Two Paradigms

## TRADITIONAL SYSTEMS



- Hierarchies
- Sequential processing
- Centralized decisions
- Predictability
- Stability
- Behavior Controlled

## COMPLEX SYSTEMS



- Networks
- Parallel processing
- Distributed decisions
- Self-organization
- Evolution
- Emergent behavior

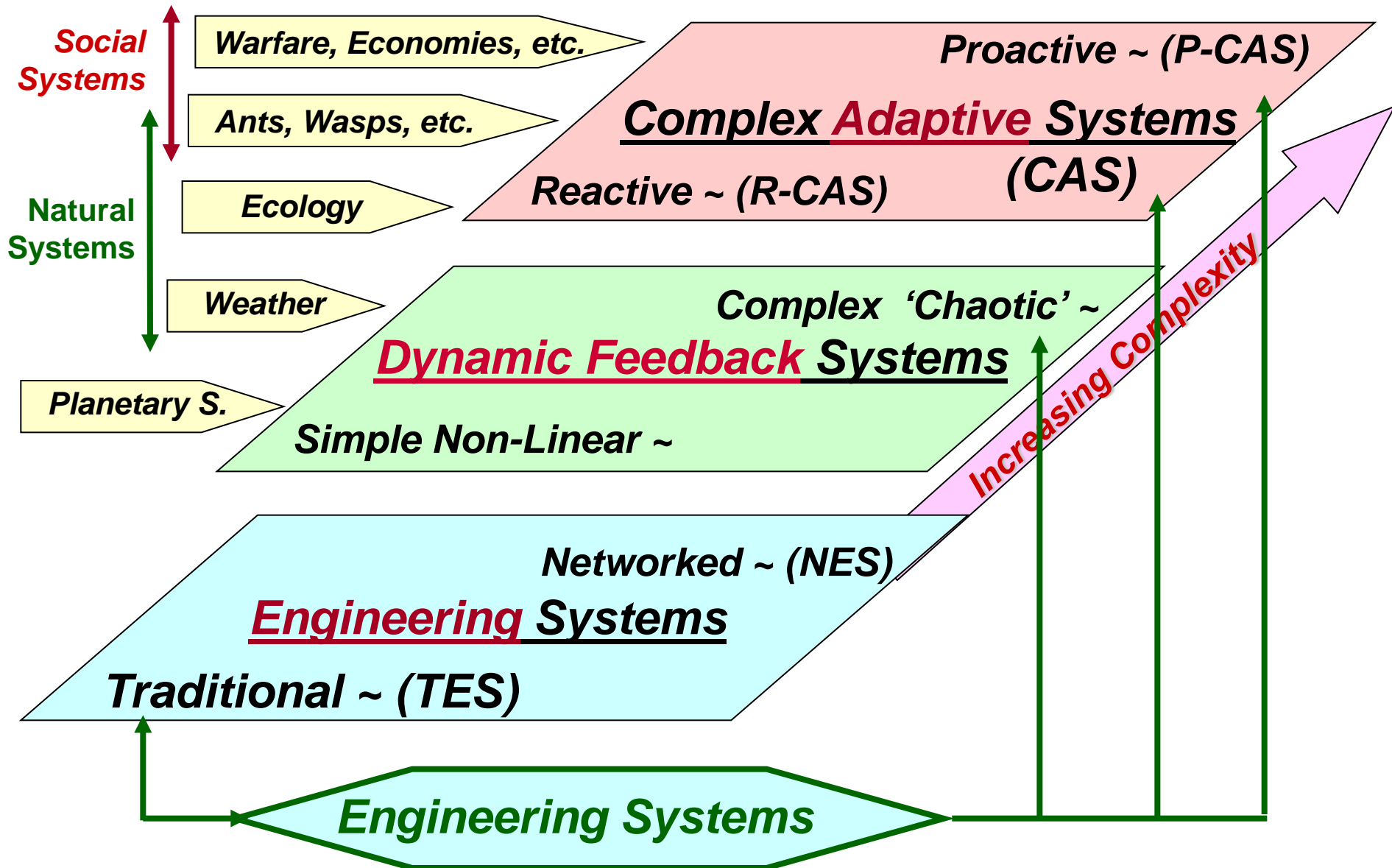
### **Generic Characteristics:**

- Co-evolution and Emergence
- Feedback and Interdependence
- Time - and Path-Dependence

### **Change of Emphasis: - From: Objects**

- To: Relationships between Entities
- From: Control
- To: Enabling infrastructures

# Systems – The Broader View



## **A. Dynamic Feedback - & Complex Chaotic Systems:**

- Can be modeled; the laws of physics are known
- Are **unpredictable**, because of (a) extreme sensitivity to initial condition and/or minor perturbations and/or (b) systems tend to be open

## **B. Reactive - CAS:** - Can be modeled; requires better understanding of the laws of nature governing adaptation

- Are **unpredictable**, because of compounding of A. & B.
- **Possibilities** for behavior and emerging states can be determined

## **C. Proactive -CAS:** - Can be modeled; need better understanding of the laws (?), if any, governing human behavior

- Are **unpredictable**, "...all bets are off !

**However: Modeling can greatly Help us  
Understand what the Future May Bring!**

## Summary:

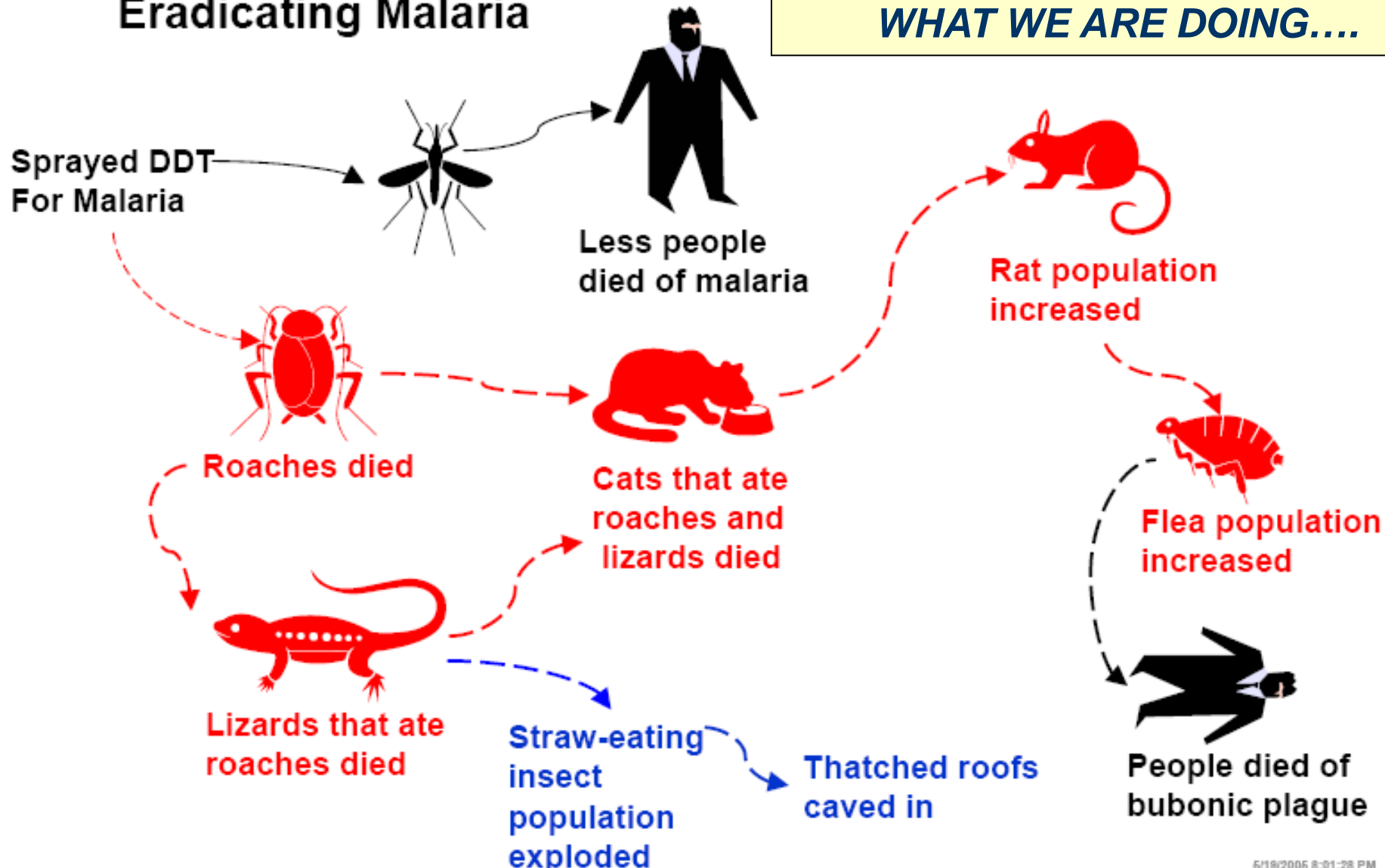
- *Inputs and outputs are not proportional*
- *The whole - is not quantitatively equal to its parts  
- may not even, qualitatively, be  
recognizable in its constituent components*
- *Cause and effect are not evident*
- *Phenomena are unpredictable,  
- but within bounds, self-organizing*
- *Unpredictability frustrates conventional planning*
- *Self-organization trumps central control*



***New ways of thinking and acting are required !***

**WE DON'T KNOW  
WHAT WE ARE DOING....**

# Eradicating Malaria



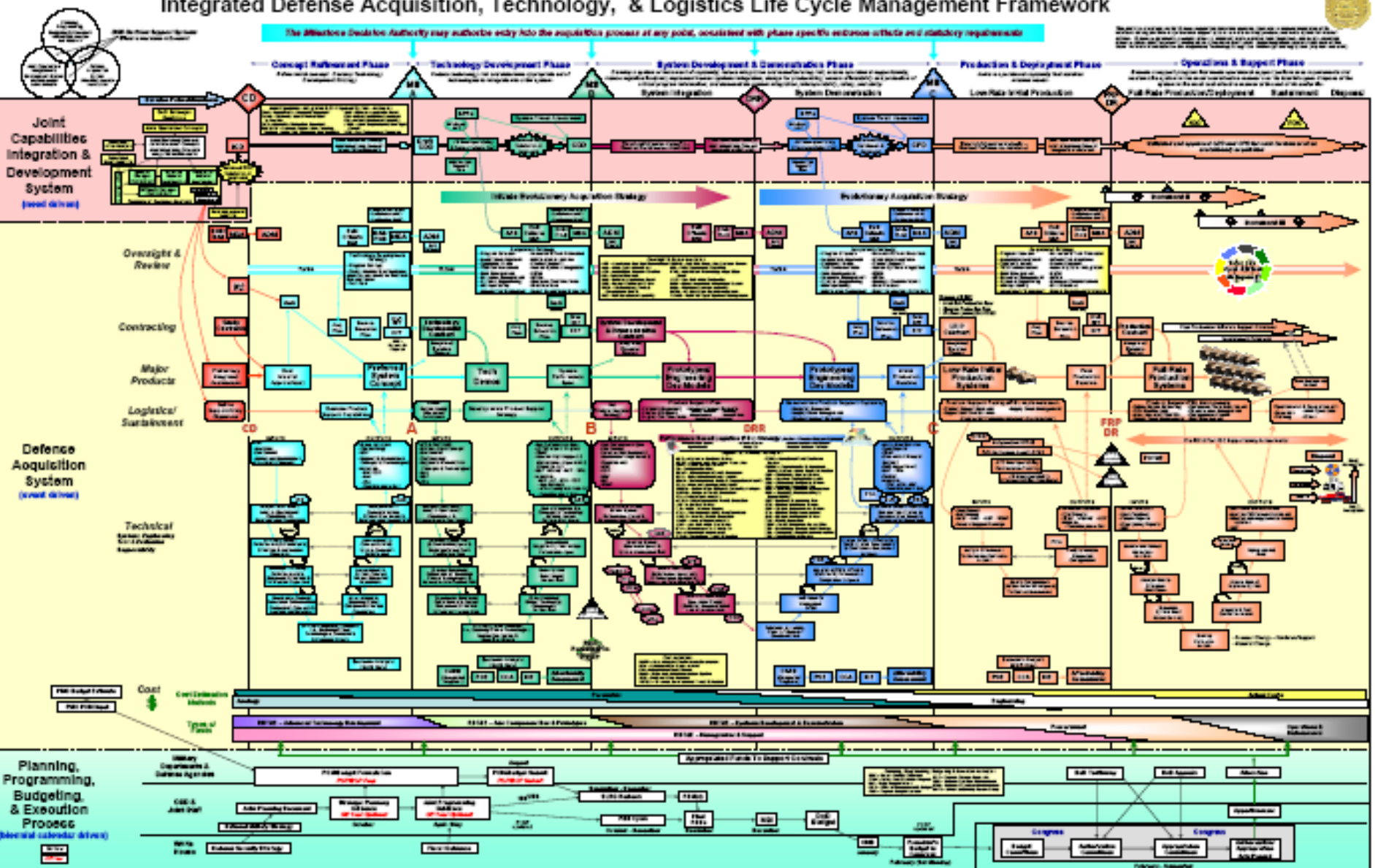


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# The Process

## Integrated Defense Acquisition, Technology, & Logistics Life Cycle Management Framework

The **Defense Decision Authority** may authorize entry into the acquisition process at any point, consistent with phase specific entrance criteria and stability requirements



# Weapon Systems Acquisition

## Some Critical Comments



EXPERIENCE. RESULTS.



- 1. The weapons *acquisition process*, which is slow, inefficient, ..... has become a burden on a defense industry already in the midst of a financial crisis.**
- 2. The defense *acquisition system* has basic problems that must be corrected. These problems are deeply entrenched and have developed over several decades from an *increasingly bureaucratic and overregulated process*.**
- 3. There is a *growing and deep concern* .... about the *DOD acquisition processes*. *Restructuring acquisition is critical and essential!***
- 4. The *existing Acquisition system* is not capable of responding to *customer needs* in this new environment. The world in which DOD must operate has *changed beyond the limits* of the existing *acquisition system's ability to adjust or evolve*.**

Note: 1. 2001 - U.S. Commission on National Security/ 21st Century

2. 1986 - Blue Ribbon Commission on Defense Management/ David Packard

3. 2005 - Dep Sec Def G. England, June 7 2005, before Congress

4. 1994 - Secretary of Defense William Perry

## The Traditional Acquisition Process:

1. Identify a Need/Threat ( or: “Capability Gap”) and Operational Concepts (“Ways”) to Defeat It
2. Explore Systems (“Means” Solutions) & Develop System Performance Requirements
3. Develop a System Meeting those Requirements

**Requirements are finalized  
before defining the System Concept**

Without System Definition, i.e., a “Means” Solution:

➡ No Valid **Cost** Estimate for New, Advanced Systems,

i.e., No Measure of **Affordability**

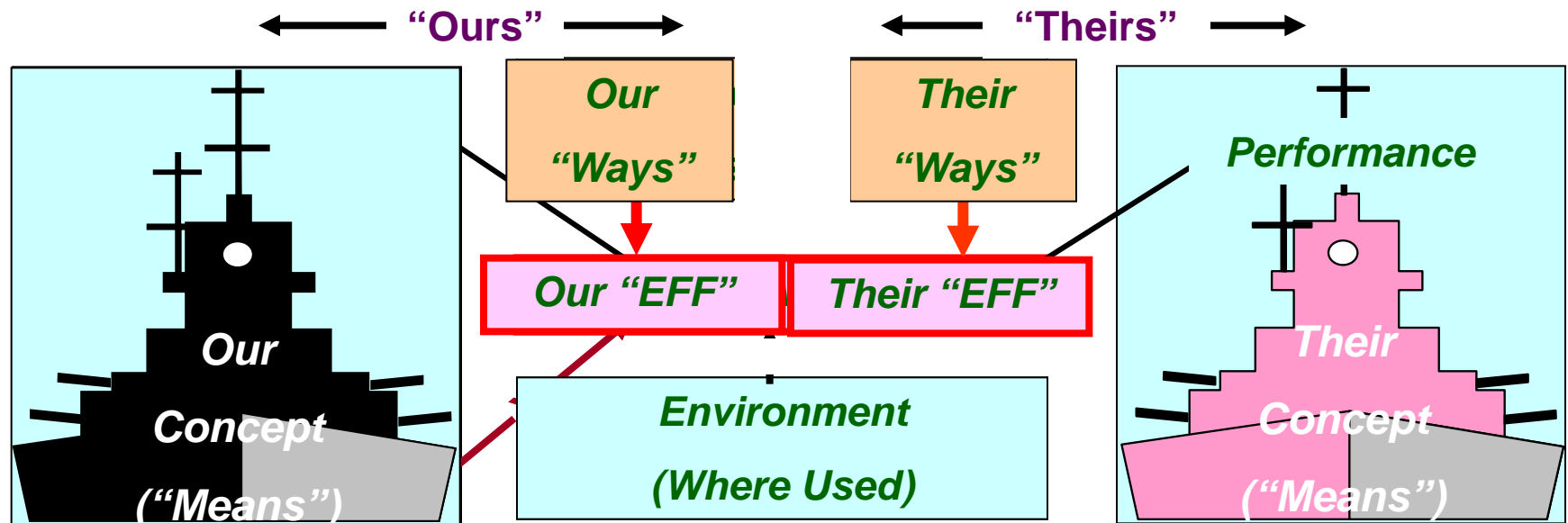
➡ No True Cost vs. **Performance** Trade-Off,

No “Quality – Quantity” Trade-Off

➡ No True “Ways” & “Means” Trade-Off

to Maximize **Effectiveness**

*(For Warfare Systems-)*



**To Establish a Relationships**

**between Effectiveness and Cost**

**Requires a Design Concept**

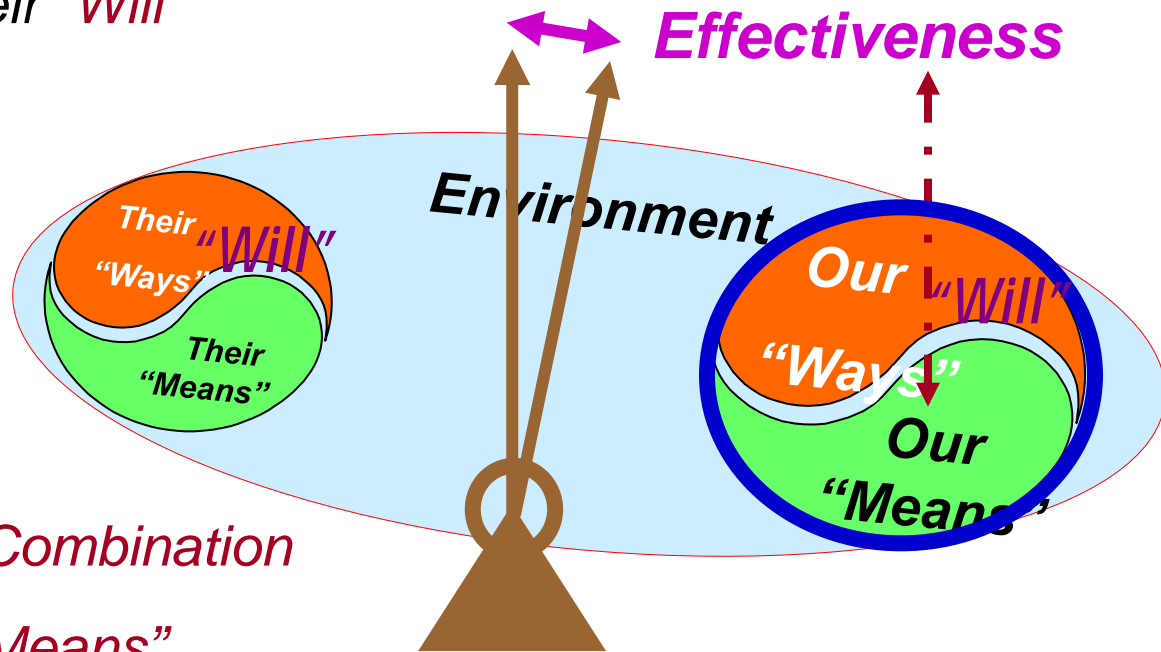
- The **link** between System *Performance* (Our “Means”) and *Effectiveness* in *CAS* is greatly **weakened** by

- *How and where* we use *Systems* (Our “Ways”),
- Their “Ways” and Their “Means”
  - Both Our ~ and Their “Will”

- Therefore:

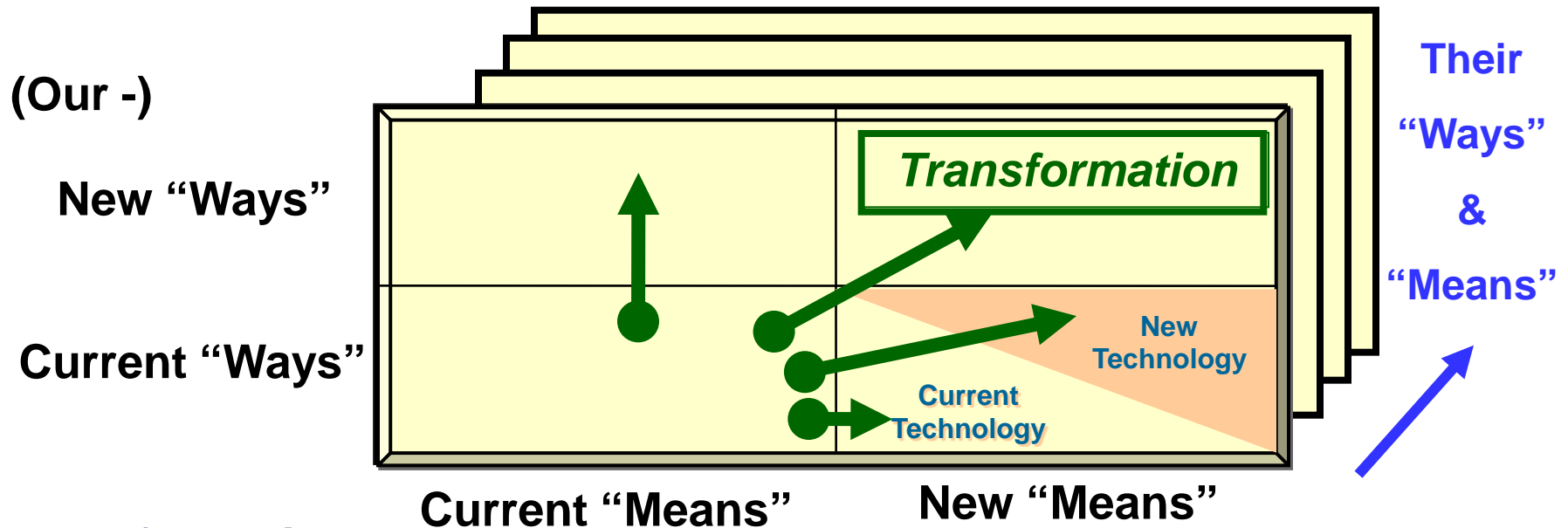
**Solutions** must be found,

- Both for Our “Means”  
and Our “Ways”,
- Representing the *Best Combination*  
of “Ways” and “Means”



.....found in the **“Ways” & “Means” Trade-Space**

# The “Ways” & “Means” Trade-Space



## Transformation:

- = New “Ways” of using our Current - and New “Means”
- While, hopefully, anticipating  
Their “Ways” and “Means” correctly

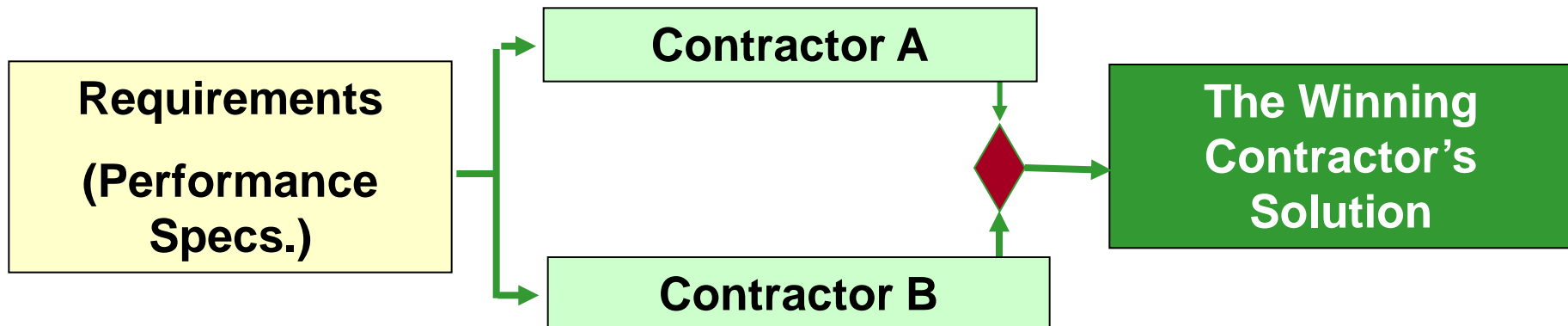
## Today’s Problem 1:

- Premature Freezing of Requirements negates fully exploring the “Ways” & “Means” Trade-Space

## Performance-Based Acquisition Links:

- *What “Means” Solution should be Acquired with*
- *Who should be the Producer*

*How well do we meet the Selection Challenge ?*



# DD21 RFP Section M – Evaluation Factors for Award



EXPERIENCE. RESULTS.

## A. Cost Criteria (55%)\*

Category 1: Ability to Meet Cost  
Boundaries & Realism (30%)

Category 2: Contract Cost (25%)

Note: \*(A>B)

\*\* (C1>C2)

\*\*\* (F1>F2,F3); (F2=F3); F2,F3>>F4)

## B. Technical, Mgmt, Past Perf. (45%)

Category 1: DD21 Sys Effectiveness (12%)\*\*\*

Category 2: FSC Mgmt (10%)

Category 3: DD21 System Technical Design (8%)

Category 4: Life Cycle Engineering & Support (8%)

Category 5: Past Performance (7%)

Note: \*\*\*\*(C1>C2): (C2>C3,C4); (C3,C4>C5)

Category 1: System Effectiveness (12%)

Factor 1: Land Attack

Factor 2: Mobility

Factor 3: Ships Crew

Factor 4: Survivability

Factor 5: Maritime Dominance

Category 2: FSC Management (10%)

Category 3: System Techn. Design (8%)

Factor 1: Total Ship Computing  
Environment

Factor 2: C4ISR

Factor 3: Combat System

Factor 4: Ship System

Category 4: Life Cycle Engineering & Support (8%)

Factor 1: Training

Factor 2: Readiness & Logistics

Factor 3: Ashore Manpower

Factor 4: Certification, T&E

Factor 5: Smart Product Model

Factor 6: Integrated Data Environment

Factor 7: Modernization & Disposal

Category 5: Past Performance (7%)

## A. (Cost Criteria (55%))

Category 1: Ability to Meet Cost Boundaries & Realism (30%)

Category 2: Contract Cost (25%)

## B. (Technical, Management, Past Performance (45%))

Category

Category

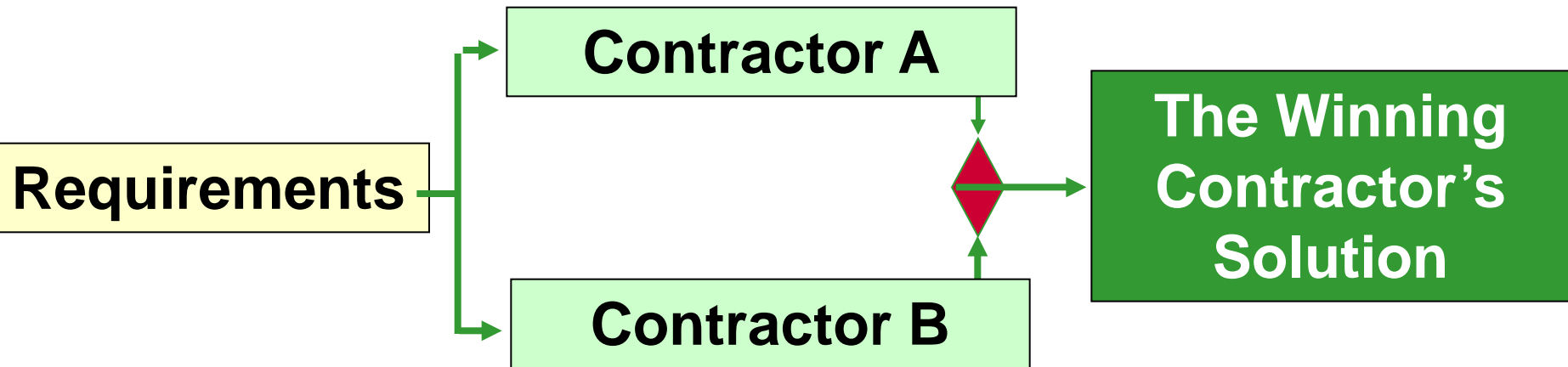
Category

Category

Category

### The Totals:

- **Design Data** **26%**
- **(Pre-existing Information:)**
  - **From DRM** **6%**
  - **Past Performance** **7%**
- **Plans & Promises** **61%**



1. It is **possible** that the Navy selects the Contractor with the **Better Concept**, - the small weight given to the technical design could make a difference
2. It is **very likely** that the Navy selects the Concept of the Contractor with the **Best Proposal Team**
3. The **best possible concept** is probably **not** even **in the running** ; there is **no synthesis** of **best sub-system solutions**

**The Solution: Next**

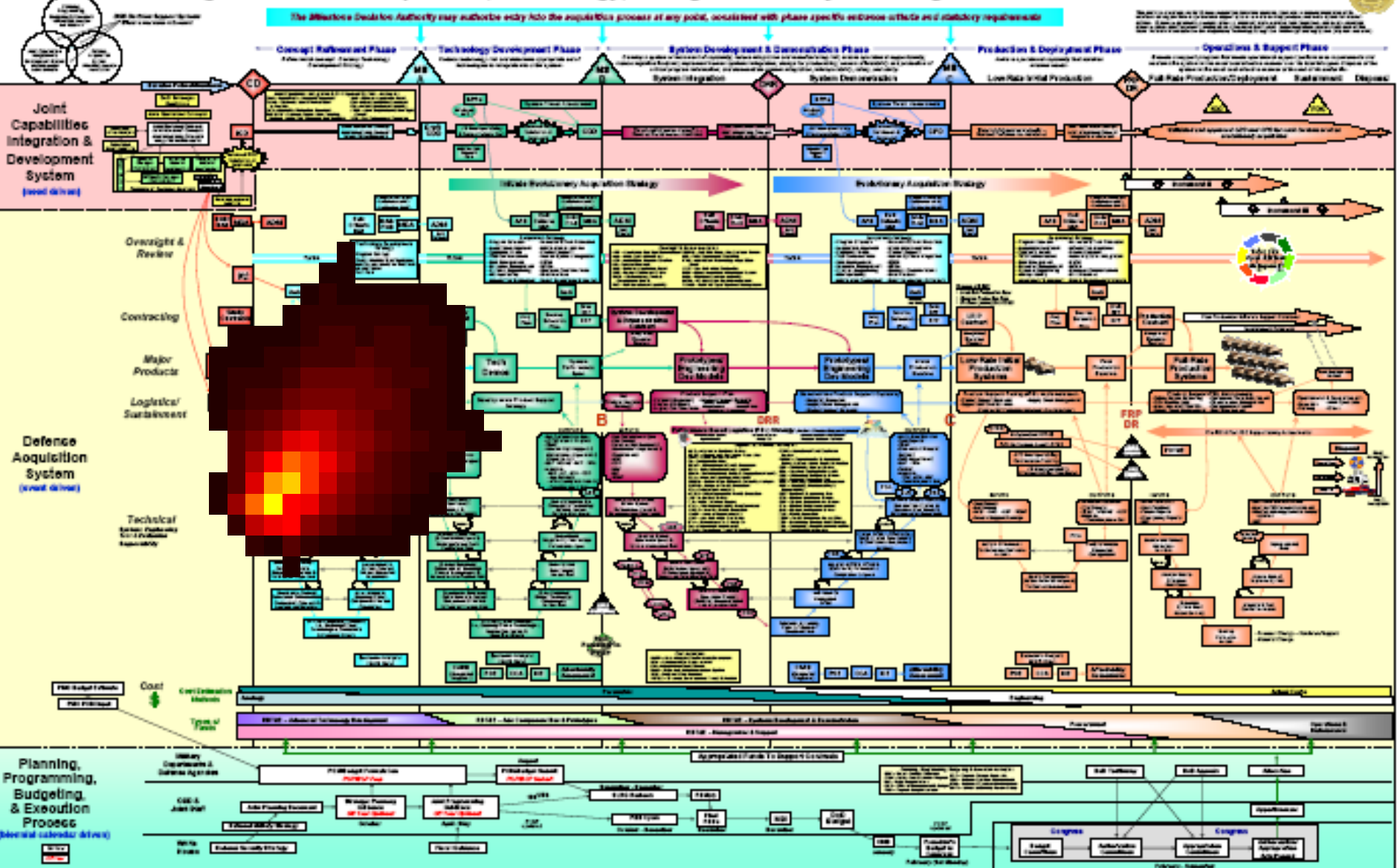


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# The Process

## Integrated Defense Acquisition, Technology, & Logistics Life Cycle Management Framework

Rev. 1.0, November 2004



# Development & Acquisition Issues



EXPERIENCE. RESULTS.

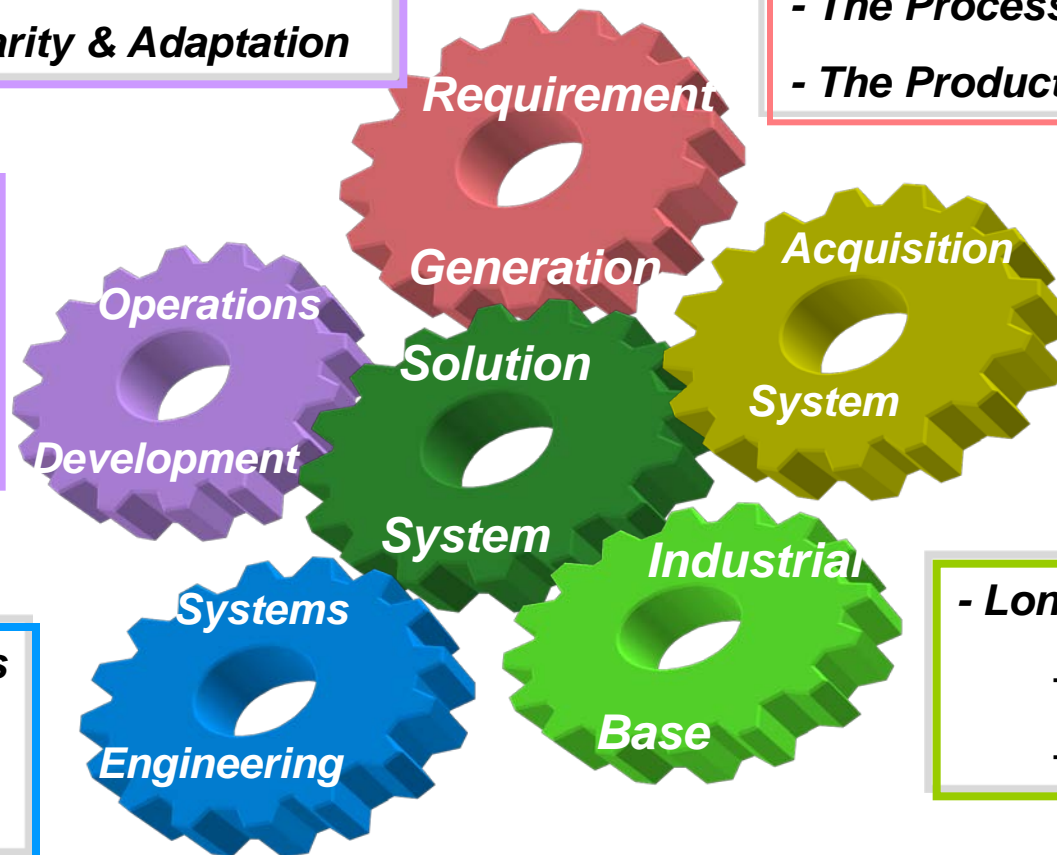
- Warfare:**
- Complexity
- Non-Linearity & Adaptation

- The Process
- The Products

## **Transportation:**

- The Route & Payload
- Speed, Range, etc

- The Process
- Contracting



- System Categories
- System Dynamics
- Trade Spaces

- Long-Term Viability
- Design
- Construction



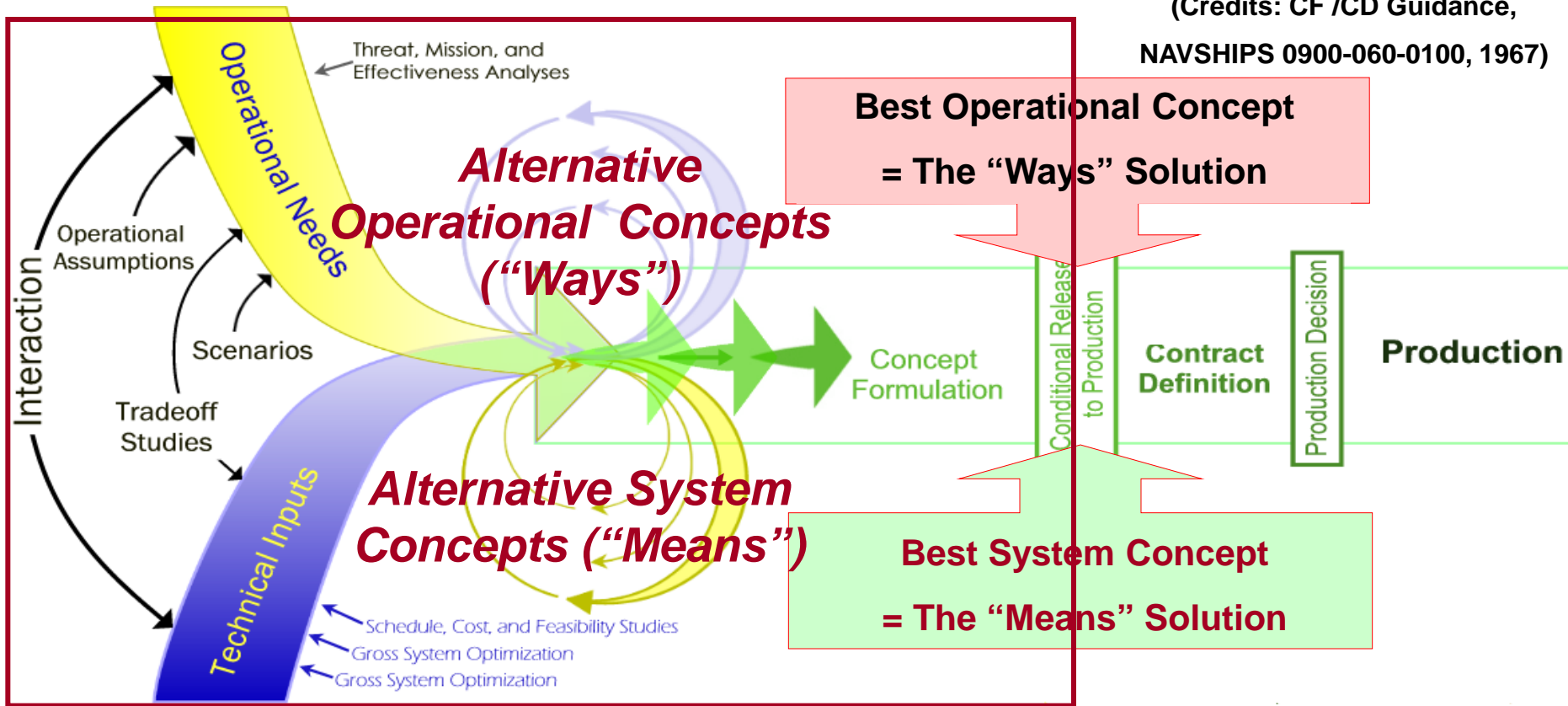
**“Solution-Based Acquisition”**

# Solution – Based Acquisition



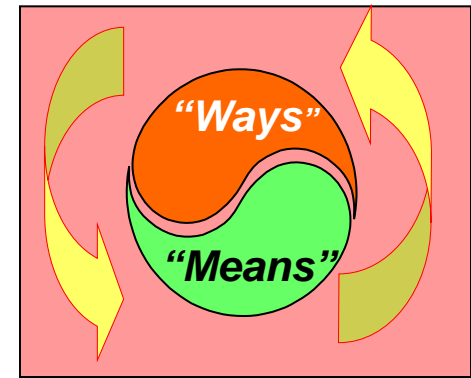
EXPERIENCE. RESULTS.

(Credits: CF /CD Guidance, NAVSHIPS 0900-060-0100, 1967)



- Concurrent Development of Warfare Concept – and Systems Solutions

- Deciding **what** System Concept to acquire **Not** : what **Performance Requirements** should be the Basis for the Acquisition



## **Phase 1. *Customer – to - Concept***

= Deciding **what system** to acquire - if any  
i.e., what **system solution**;  
- **not** : what system **performance**

## **Phase 2. *Concept – to - Contract***

= Defining it in greater detail &  
deciding who should build it

## **Phase 3. *Contract – to - Commissioning***

= Developing final details & building it

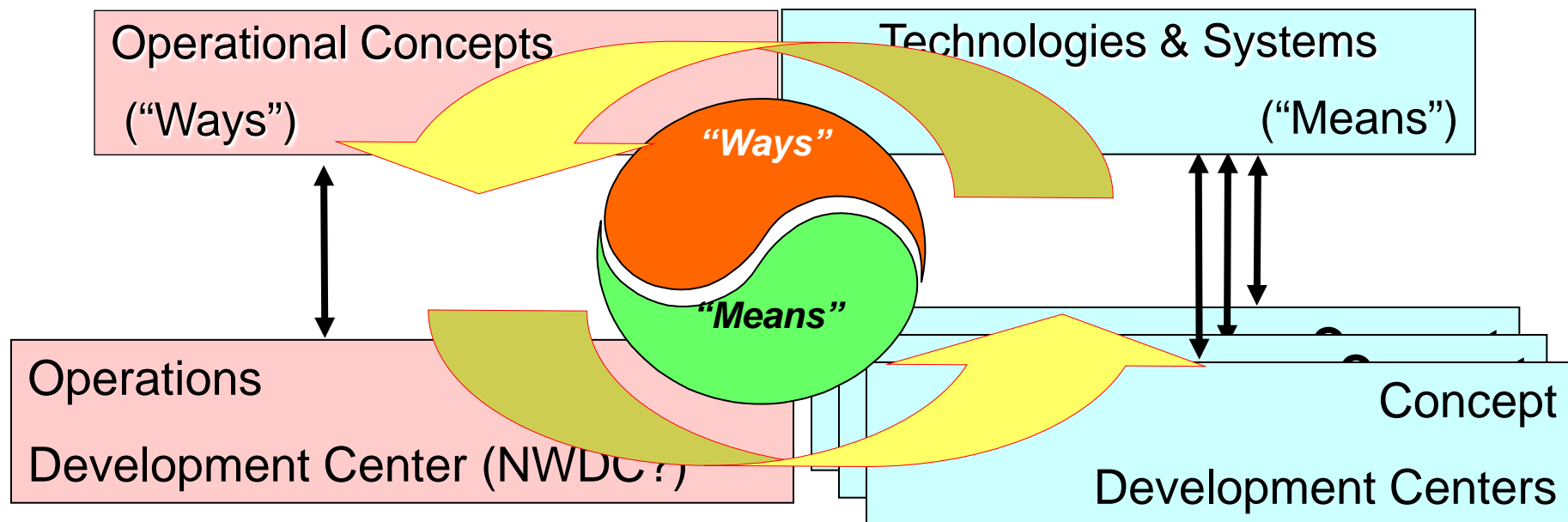
**→ *The Solution-Based Model (SBM)***

# Organizational Integration



EXPERIENCE. RESULTS.

Industry	DARPA	ONR	SPAWAR	NAVAIR	NAVSEA/ NSWC / NUWC	SSG	NWDC	OPNAV	ONI	MCCDC	JCS
Platform and systems	S&T	S&T	Battleforce C <sup>4</sup> I	Aviation Concepts	Total Ship Concept Design/R&D	Future Capabilities	Fleet, CONOPS,	Strategies Fleet Arch	Threat INTEL	USMC Strategies	Joint Strategies



• *Establish Integration Centers of Excellence - Virtually "Co-Located"!*

Corporate Memory + Organizational Maturity + Knowledge Currency



***(Surely: No...)***

***.....Questions***