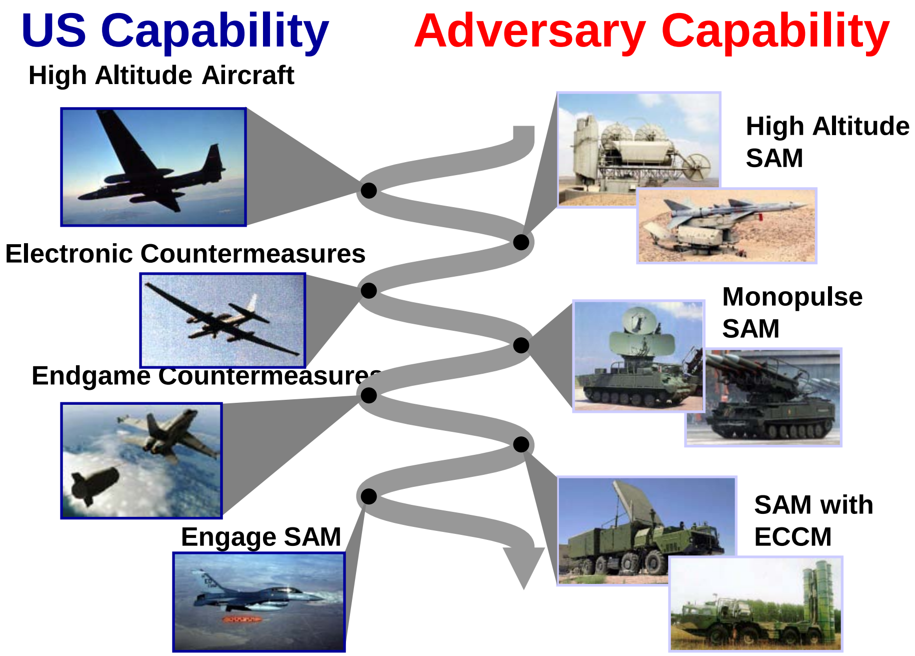
Physics-Based Modeling: What We Can Do While We're Waiting

Dr. Robert Neches
Director, Advanced Engineering Initiatives
Office of the Deputy Assistant Secretary of Defense for Systems Engineering

NDIA Conference on Physics-Based Modeling
16 November 2011

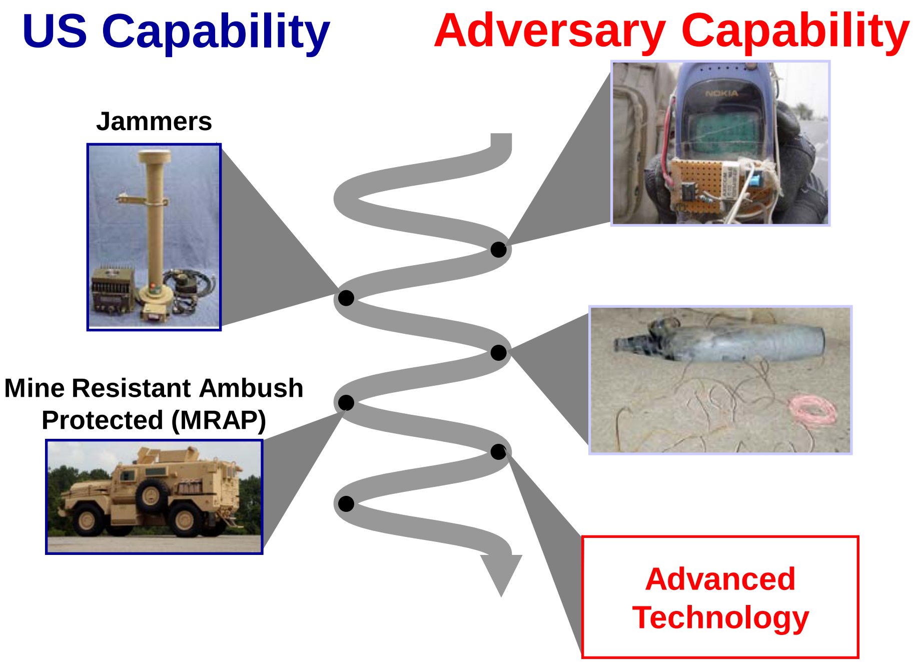
The Timeline has Collapsed (For Military Systems)!

Conventional Warfare



RESPONSE LOOP MEASURED IN YEARS OR DECADES

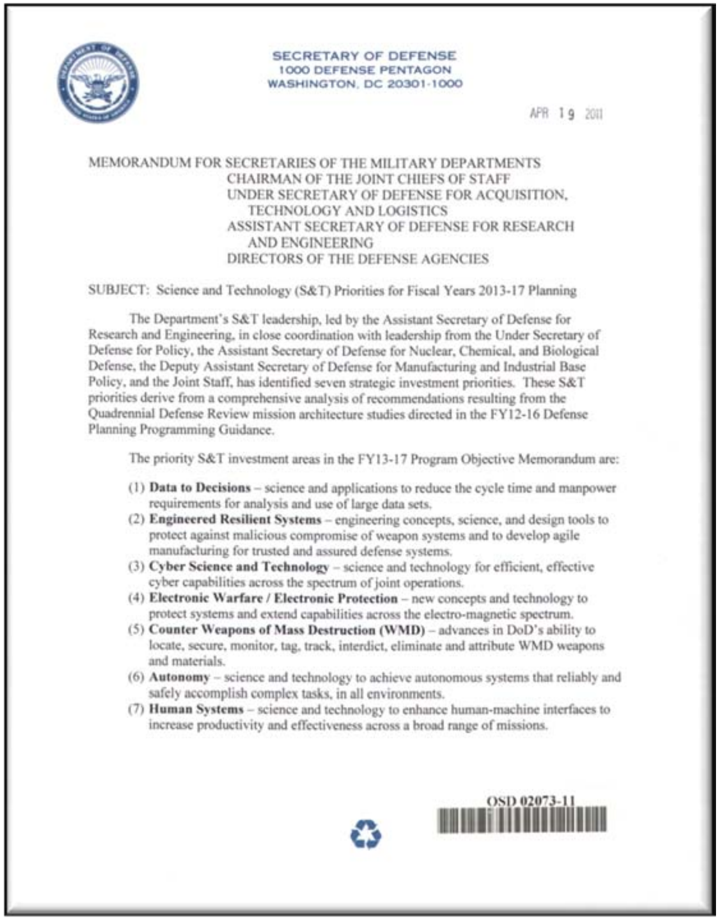
Counter-Insurgency Warfare



Response loop measured in *months or weeks*

DoD S&T Focus Areas

SECDEF Guidance



SECRETARY OF DEFENSE
1000 DEFENSE PENTAGON
WASHINGTON, DC 20301-1000

APR 19 2011

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY AND LOGISTICS
ASSISTANT SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING
DIRECTORS OF THE DEFENSE AGENCIES

SUBJECT: Science and Technology (S&T) Priorities for Fiscal Years 2013-17 Planning

The Department's S&T leadership, led by the Assistant Secretary of Defense for Research and Engineering, in close coordination with leadership from the Under Secretary of Defense for Policy, the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense, the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy, and the Joint Staff, has identified seven strategic investment priorities. These S&T priorities derive from a comprehensive analysis of recommendations resulting from the Quadrennial Defense Review mission architecture studies directed in the FY12-16 Defense Planning Programming Guidance.

The priority S&T investment areas in the FY13-17 Program Objective Memorandum are:

(1) **Data to Decisions** – science and applications to reduce the cycle time and manpower requirements for analysis and use of large data sets.
(2) **Engineered Resilient Systems** – engineering concepts, science, and design tools to protect against malicious compromise of weapon systems and to develop agile manufacturing for trusted and assured defense systems.
(3) **Cyber Science and Technology** – science and technology for efficient, effective cyber capabilities across the spectrum of joint operations.
(4) **Electronic Warfare / Electronic Protection** – new concepts and technology to protect systems and extend capabilities across the electro-magnetic spectrum.
(5) **Counter Weapons of Mass Destruction (WMD)** – advances in DoD's ability to locate, secure, monitor, tag, track, interdict, eliminate and attribute WMD weapons and materials.
(6) **Autonomy** – science and technology to achieve autonomous systems that reliably and safely accomplish complex tasks, in all environments.
(7) **Human Systems** – science and technology to enhance human-machine interfaces to increase productivity and effectiveness across a broad range of missions.

OSD 02073-11

19 April 2011

Complex Threats

Electronic Warfare / Electronic Protection

Cyber Science and Technology

Counter Weapons of Mass Destruction

Force Multipliers

Autonomy

Data-to-Decisions

Human Systems

Engineered Resilient Systems

Engineered Resilient Systems (ERS): A DoD Perspective

"...our record of predicting where we will use military force since Vietnam is perfect. We have never once gotten it right.

There isn't a single instance ... where we knew and planned for such a conflict six months in advance, or knew that we would be involved as early as six months ahead of time.

... we need to have in mind the greatest possible flexibility and versatility for the broadest range of conflict..."

The Honorable Dr. Robert M. Gates
22nd Secretary of Defense
24 May 2011

Deputy Secretary of Defense Ashton Carter is charged with, "...eliminating wasteful spending, consolidating duplicative functions, and driving ongoing and new efficiencies initiatives that can help us achieve the aggressive budgetary goals we have set."

The Honorable Leon Panetta
23rd Secretary of Defense
6 Oct 2011

ERS: a DoD-wide science and technology priority

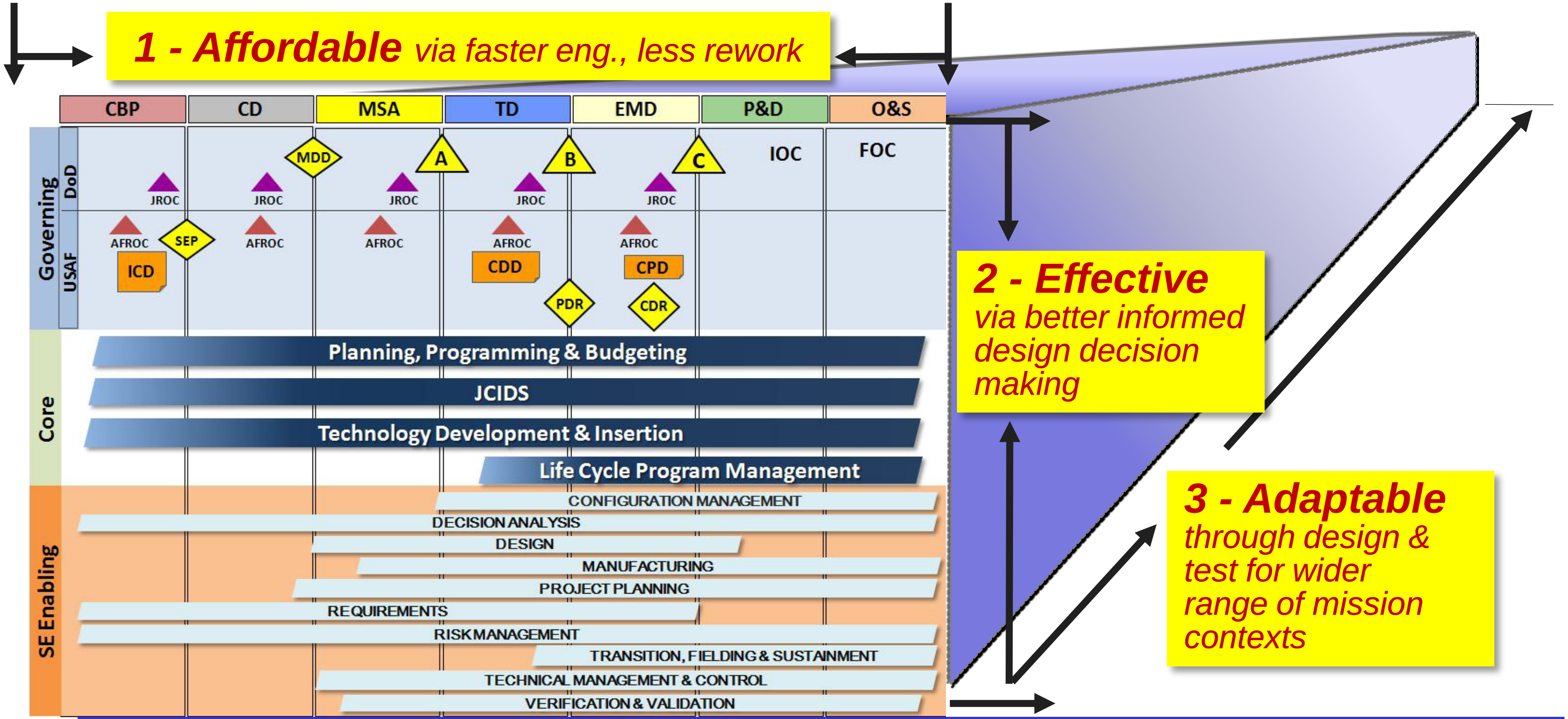
– Established to guide FY13-17 defense investments across DoD

– Ten year science and technology roadmap under development

– Five technology enablers identified

Engineered Resilient Systems Spans the Systems Life cycle

Resilience: Effective in a wide range of situations, readily adaptable to others through reconfiguration or replacement, with graceful and detectable degradation of function



Uncertain futures, and resultant mission volatility, require affordably adaptable and effective systems – done quickly

The Problem Goes Beyond Process:
Need New Technologies, Broader Community

Today

Rapidly necks down alternatives

Decisions made w/o info

50 years of process reforms haven't controlled time, cost and performance

Rqmts1
AoA
Competing designs
Eng. design
Rqmts2
Risk reduction
T&E
Redesign
T&E
Compete LRIP
Etc.

Sequential and slow

Information lost at every step

Ad hoc reqmts refinement

The Future

Fast, easy, inexpensive up-front engineering:

- Automatically consider many variations
- Propagate changes, maintain constraints
- Introduce and evaluate many usage scenarios
- Explore technical & operational tradeoffs
- Iteratively refine requirements
- Adapt and build in adaptivity
- Learn and update

New tools help Engineers & Users understand interactions, identify implications, manage consequences

Engineered Resilient Systems: Needs and Technology Issues

Creating & fielding affordable, effective systems entails:

- **Deep trade-off analyses across mission contexts**
  - **Adaptability, effectiveness and affordability in the trade-space**
  - **Maintained for life**
- **More informative requirements**
- **Well-founded requirements refinement**
- **More alternatives, maintained longer**

Doing so quickly and adaptably requires new technology:

- **Models with representational richness**
- **Learning about operational context**
- **Uncertainty- and Risk- based tools**

Starting point: Model- and Platform- based engineering

System Representation and Modeling: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Capturing • ***Physical and logical structures*** • ***Behavior*** • ***Interaction with the environment and other systems***	**Model 95% of a complex weapons system**	• Combining live and virtual worlds • Bi-directional linking of physics-based & statistical models • Key multidisciplinary, multiscale models • Automated and semi-automated acquisition techniques • Techniques for adaptable models

We need to create and manage many classes (*executable, depictional, statistical...*) and many types (*device and environmental physics, comms, sensors, effectors, software, systems ...*) of models

System Representation and Modeling: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Capturing • ***Physical and logical structures*** • ***Behavior*** • ***Interaction with the environment and other systems***	**Model 95% of a complex weapons system**	• Combining live and virtual worlds • Bi-directional linking of physics-based & statistical models • Key multidisciplinary, multiscale models • Automated and semi-automated acquisition techniques • Techniques for adaptable models

We need to create and manage many classes (*executable, depictional, statistical...*) and many types (*device and environmental physics, comms, sensors, effectors, software, systems ...*) of models

Characterizing Changing Operational Environments: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Deeper understanding of warfighter needs ***Directly gathering operational data*** ***Understanding operational impacts of alternatives***	**Military Effectiveness Breadth Assessment Capability**	• Learning from live and virtual operational systems • Synthetic environments for experimentation and learning • Creating operational context models (missions, environments, threats, tactics, and ConOps) • Generating meaningful tests and use cases from operational data • Synthesis & application of models

"Ensuring adaptability and effectiveness requires evaluating and storing results *from many, many scenarios* (including those presently considered unlikely) *for consideration earlier* in the acquisition process."

Cross-Domain Coupling: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps

Better interchange between incommensurate models
 	
Resolving temporal, multi-scale, multi-physics issues
	Weapons system modeled fully across domains	• Dynamic modeling/analysis workflow
		• Consistency across hybrid models
		• Automatically generated surrogates
		• Semantic mappings and repairs
		• Program interface extensions that:
		  • Automate parameterization and boundary conditions
		  • Coordinate cross-phenomena simulations
		  • Tie to decision support
		  • Couple to virtual worlds

Making the wide range of model classes and types work together effectively requires new computing techniques (not just standards)

Tradespace Analysis: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Efficiently generating and evaluating alternative designs ***Evaluating options in multi-dimensional tradespaces***	**Trade analyses over *very large* condition sets**	• Guided automated searches, selective search algorithms • Ubiquitous computing for generating/evaluating options • Identifying high-impact variables and likely interactions • New sensitivity localization algorithms • Algorithms for measuring adaptability • Risk-based cost-benefit analysis tools, presentations • Integrating reliability and cost into acquisition decisions • Cost-and time-sensitive uncertainty management via experimental design and activity planning

Exploring more options and keeping them open longer, by managing complexity and leveraging greater computational testing capabilities

Collaborative Design & Decision Support: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Well-informed, low-overhead collaborative decision making	**Computational / physical models bridged by 3D printing** ***Data-driven* trade decisions executed and recorded**	• Usable multi-dimensional tradespaces • Rationale capture • Aids for prioritizing tradeoffs, explaining decisions • Accessible systems engineering, acquisition, physics and behavioral models • Access controls • Information push-pull without flooding

ERS requires the transparency for many stakeholders to be able to understand and contribute, with low overhead for participating

Issues in Building an Engineered Resilient Systems S&T Community

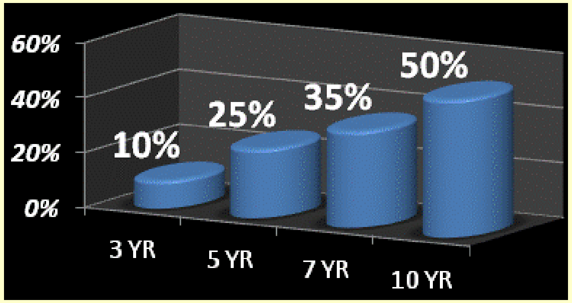
- **Complex integration across many technologies:**
  - Interdisciplinary across air, land, sea for electromechanical systems with embedded control computational capabilities
  - Spans the engineering lifecycle: Concept engineering and analysis, Design & Prototyping, Development, Production, Sustainment
  - New tools, methods, paradigms:
    Linking engineers, decisionmakers, other stakeholders
  - Addressing product *robustness*, engineers' *productivity*, and systemic *retention of options*

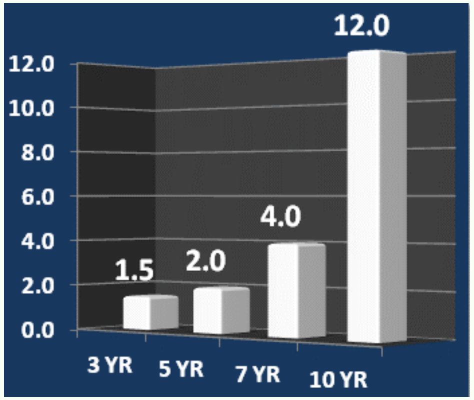
- **Nascent, emerging ties to basic science, e.g.:**
  - Computational Approximate Representations:
    Can't get all engineering tools talking same language
  - Mathematics and Computational Science of Complexity:
    Can't look at every engineering issue, need aids to determine focus
  - Mathematics and Cognitive Science of Risk, Sensitivity, and Confidence:
    Need decision aids for understanding implications of trades, committing $

What Constitutes Success?

Adaptable (and thus robust) designs

– Diverse system models, easily accessed and modified
– Potential for modular design, re-use, replacement, interoperability
– Continuous analysis of performance, vulnerabilities, trust
– ***Target: 50% of system is modifiable to new mission***



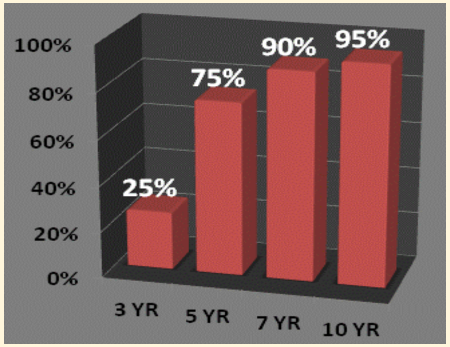


Faster, more efficient engineering iterations

– Virtual design – integrating 3D geometry, electronics, software
– Find problems early:
– Shorter risk reduction phases with prototypes
– Fewer, easier redesigns
– Accelerated design/test/build cycles
– ***Target: 12x speed-up in development time***

Decisions informed by mission needs

– More options considered deeply, broader trade space analysis
– Interaction and iterative design among collaborative groups
– Ability to simulate & experiment in synthetic operational environments
– ***Target: 95% of system informed by trades across ConOps/env.***



Envisioned End State

Improved Engineering and Design Capabilities

- More environmental and mission context
- More alternatives developed, evaluated and maintained
- Better trades: managing interactions, choices, consequences

Improved Systems

- Highly effective: better performance, greater mission effectiveness
- Easier to adapt, reconfigure or replace
- Confidence in graceful degradation of function

Improved Engineering Processes

- Fewer rework cycles
- Faster cycle completion
- Better managed requirements shifts

PoC: Dr. Robert Neches, Robert.Neches@osd.mil
ODASD(SE), Rm 3C160, 3040 Defense Pentagon, Washington, DC 20301