Humans-In-The-Loop - Challenges in a Complex SoS Environment

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Topics

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- Summary Comments on Engineering in the Cognitive and Social Domains

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The Human As a Key Consideration in SoS

- **Several items of note in the US AF Science Advisory Board (SAB) Report [1] referring to the human in the equation:**
  - "An effective system-of-systems will promote collaborative decision-making and shared situation awareness amongst the human operators."
  - "…we should recognize that human-to-human and human-to-system interactions would continue to be critical components of effective systems-of-systems.
- Research in human system interaction and decision-making is required to understand better how to integrate these elements into an effective system-of-systems architecture.
  - Systems Engineering: human machine interface (HMI) was the focus for a single system; human-to-system and human-to-human interaction is the focus for SoS

[1] ***US AFSAB,*** **Executive Summary and Annotated Brief, SAB-TR-05-04, July 2005**

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Some Conclusions from US AF SAB

- "We have identified four main factors that require consideration in improving System-of-Systems Engineering in the Air Force:
  - The first of these were the need to include human system interaction as a part of System-of-Systems Engineering
  - ….. The last is the need to incorporate discovery learning through experimentation at the system-of-systems level"[1]

- "… the current state of systems engineering does not adequately support the development of complex, adaptive, and software-intensive system-of-systems (SoS) in which humans are parts of the system."[1]

- "While significant progress has been made with the network dimension, only preliminary work to scope the requirements for the human dimension of NCW has been undertaken. The cumulative effort required to realise the human dimension of NCW could well outstrip the more readily understood network aspects of NCW." "…[A key goal is to] Explore the human dimensions of the networked force and initiate changes in doctrine, education and training with appropriate support mechanisms."[2]

[1] ***US AFSAB,*** **Executive Summary and Annotated Brief, SAB-TR-05-04, July 2005**

[2] **NCW Roadmap, Australian Government, Department of Defence, 2005**

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Background

- **Net Centric Operations Imply**
  - Leverage SoS in new and different ways
  - "Potential" for decision makers and operators to
    - Unprecedented access to information and assets over the network
    - More effective and efficient human "networking"
    - Faster and more effective resource utilization
    - Faster versus smarter decisions?
- **Engineering for the Human –In-The-Loop (HITL) in a SoS**
  - Evolving area of research
    - But, implementation ahead of application of theory
      - e.g., in NCO - more sources, more deconfliction, more sensemaking required
    - Solution: Historically, engineer through experimentation
    - Dilemma: But what do we need to measure and for what purpose?

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Implication from DOTMPLF on System Engineering

- NetCentric SoS implies breaking organizational barriers
- The key human element here is Trust
  - We must not only re-engineer our system to leverage NetCenricity, we must also re-engineer the enterprise
    - Will the system from organization A be there to support the system from organization B?
- Today – Mismatch between rate of applying technology to the problem versus the organizational and business implication of the transformation
  - All facets pf DOTMPLF must be re-evaluated when a new capability must be assessed against NetCentric principles

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Observations on Human Systems Integration (HSI)

- "In HSI, decision makers and facilitators take advantage of technological developments in systems engineering and systems management. Inherent in several of these advances is the capability to quantify and measure human characteristics. These newer methods also allow better decisions to be made early in the design and development process where changes are relatively inexpensive to make."[1]
  - Supports the broad implications of DOTMPLF in Capability Development
  - Need: Greater focus on HITL as a measurable component of capability MOE and its implementation in SoS (systems + humans) MOP
  - Trend: Systems and products that can be operated and repaired by fewer people, by lesser skilled people, and/or people with lesser training will be in greater demand.
    - Manpower, personnel, and training (example: UAV and takeoff/landing expertise) are becoming key consideration in cost effectiveness and mission effectiveness
- Need to make the human component an "inherent part of the system," and the drive toward "quantification of people variables" in the overall system engineering of the system or SoS

[1] *"Handbook of Human Systems Integration", Harold Booher, Wiley & Sons, 2005*

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Observations on Human Systems Integration (HSI)

- NetCentric SoS - The human is now taking an active and leading role in combining systems to provide new capabilities (at run time versus at design time)
  - How that is done and how effectively is now an art.
  - Can we bring science to this?
  - If we are passing Power to the Edge, we have a new training paradigm with new SoS assets to configure and use.
  - Commanders are challenged to plan tasks in hours vs. days; planning in minutes versus hours
    - Paradigm shift: Less decision and information flow up and down the chain of command
    - Commander now "shepherds" or "monitors" versus "commands"
    - What is the minimum information required to make decisions at the Edge?
  - How do we capture and analyze the impact of an operational architecture, and its complementary system architectures, when we are asked to accommodate responsive, agile, dynamic (on-the-fly changes to) operational approaches in a NetCentric environment?
- "….it can be expected that HSI activities will become more closely associated with constructive, virtual, and live simulations" [1]
  - Measurement of Human-in-the-loop parameters (primarily cognitive and social parameters) has been problematic for SEs to define and measure
  - Experimentation, in lieu of engineering, has been pursued

[1] *"Handbook of Human Systems Integration", Harold Booher, Wiley & Sons, 2005*

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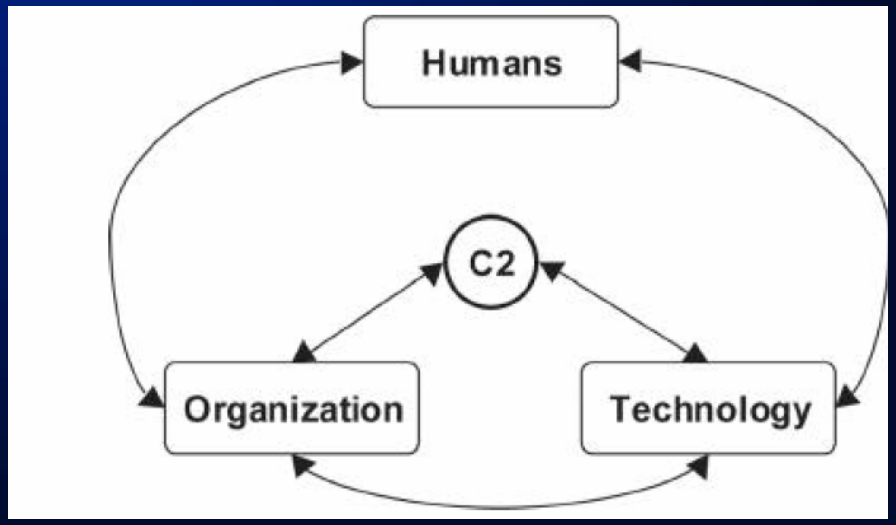
The C2 Environment Triad

- "…the character and performance of a C2 system may change as anyone of elements in these three categories changes." [1]
- "…since the human, organizational and technological elements are closely linked in most cases, optimizing each one of them at a time under ceteris paribus [other things being equal] assumptions for the other two rarely ever results in an efficient C2 system."[2]



[1] NATO Code of Best Practice for C² Assessment, CCRP, 2002

[2] Schot, J., & Rip, A. (1996). The past and future of constructive technology assessment. In *Technological forecasting and social change, 54*, 251-268. New York: Elsevier Science. [Chapter 6]

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Observation from the Perspective of Operations Analysts

- **Pearls of Wisdom[1]**
  - We can no longer expect to "bend" people to technology; rather, we need to study how best to produce creativity at the nexus of people and technology
  - Needs are not always task related
  - Needs may be cognitive, behavioral, or social, such as how information is displayed, how teams operate, how tasks are shared
  - We must recognize the importance of relationships [read “trust”]
  - Technical solutions cannot replace human judgment

[1] MORS Workshop Report: How Cognitive and Behavioral Factors Influence Command and Control, Military Operations Research Society, 22 April 2005

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Observation from the Perspective of Operations Analysts

- **Pearls of Wisdom[1] (cont'd)**
  - Decision making tasks
    - How much information is enough to make a decision?
    - The lower the tolerance for risk, the higher the demand for information to avoid that risk
    - Commanders manage information differently, therefore, information must be shaped for the individual commander
  - Tasks do not always require quantifiable information
  - Just because something cannot be measured or quantified, doesn't mean it isn't important
    - Qualitative methods, such as observation, have their uses as well
  - Commanders must perform their tasks in a timely manner
    - Concern that they will wait for more or better information rather than act or make a decision
    - Need to balance the need for quick decision making with informed decision making

[1] MORS Workshop Report: How Cognitive and Behavioral Factors Influence Command and Control, Military Operations Research Society, 22 April 2005

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Observation from the Perspective of Operations Analysts[1]

- On the Network - Email, phone, and chat proliferate workload irrespective of the chain of command
- Increased capability may decrease effectiveness (more technology, information overload)
- Concern - In Network-Centric Warfare, everything depends on the network - What if it doesn't work?

[1] MORS Workshop Report: How Cognitive and Behavioral Factors Influence Command and Control, Military Operations Research Society, 22 April 2005, p.22

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Considerations for Systems Engineering

- **System Engineering tradeoffs**
  - Drivers in the problem space
    - Changing nature of military operations (sectarian-based urban vs national armies
    - Call for certain cognitive and social behavior
      - e.g., each system optimized for human in that domain – SoS human behavior yet to be characterized
  - Requirements in terms of the human component of the architecture
    - As opposed to mission, task, or technology
      - Examples
        - Agility and adaptability refers to the human, rather than the command and control process.
        - Distributed collaboration refers to the people who collaborate, rather than the tools used to collaborate.
  - Technology can work well, but still not contribute to battlefield performance

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Net Centric Operations Conceptual Framework (NOCF)

- NOCF[1] consist of the physical, information, cognitive, and social domains
- The domains are inextricably linked in the NCO environment
- All the domains must support processes carried out during Effects-Based Operations, if they are to be of any value
- The ingestion of information about the battlespace, conversion into information, and creating awareness as the basis for action are fundamental tasks in the cognitive domain
  - These are uncomfortable attributes for systems engineers to deal with in their design
  - Yet they are central to successfully leveraging NCO
- How do we design for the mantra "the right information to the right person at the right place in the right form"?
  - If requirements are static, engineering is straightforward
  - Challenge: How do human decision makers perceive the actions in the physical domain as reported to them? And then how do they make the decision?
  - Understanding this comes down to how people process information and under what mental models
  - Complexity and uncertainties are the norm here

[1] *Net Centric Operations Conceptual Framework, Version 2, OSD/OFT/NII, June 2004*

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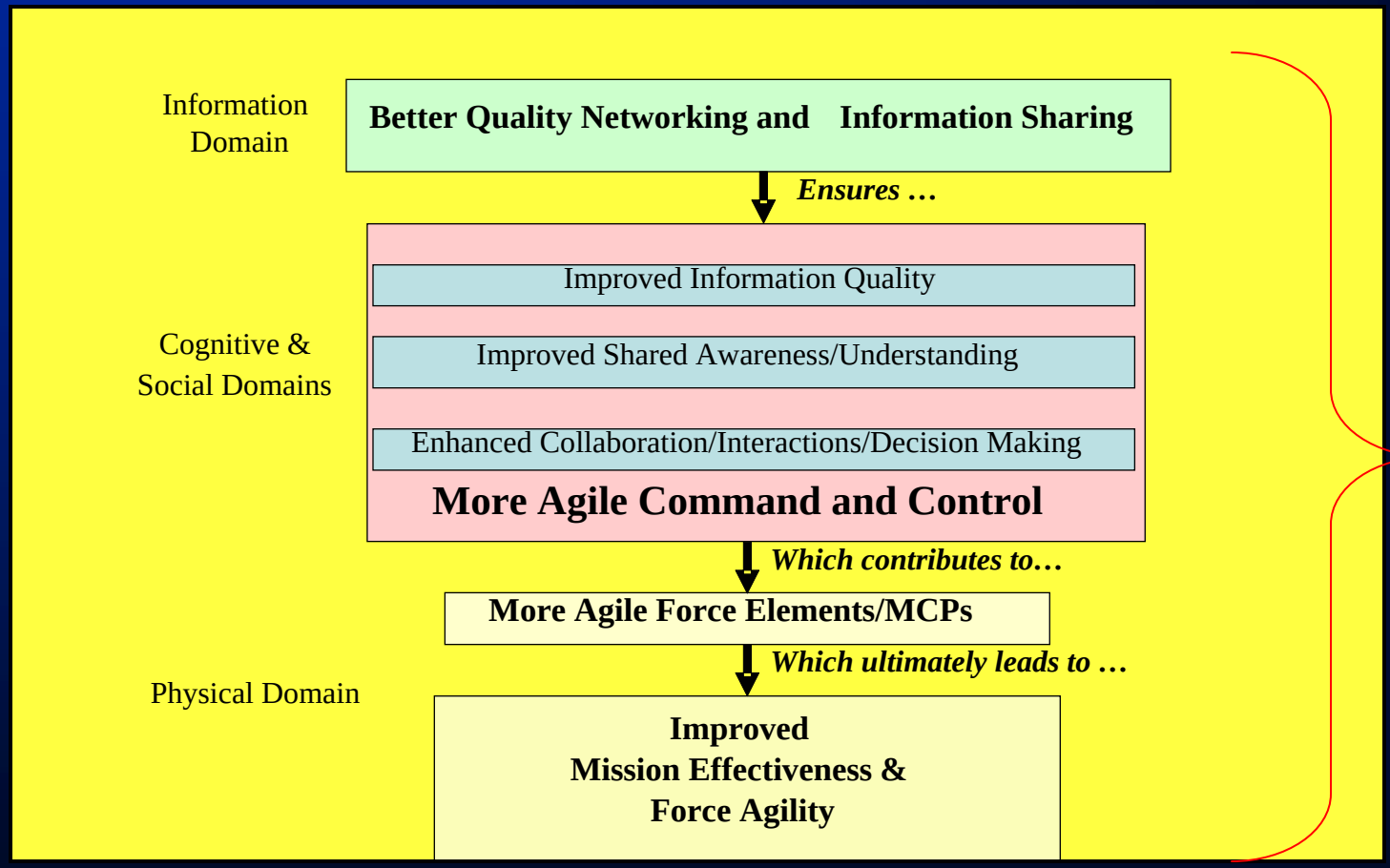
NetCentric Operational Conceptual Framework (NOCF)

- **The human and organizational components will influence the cognitive and social domains of the NCOF**



[1]*Net Centric Operations Conceptual Framework, Version 2, OSD/OFT/NII, June 2004*

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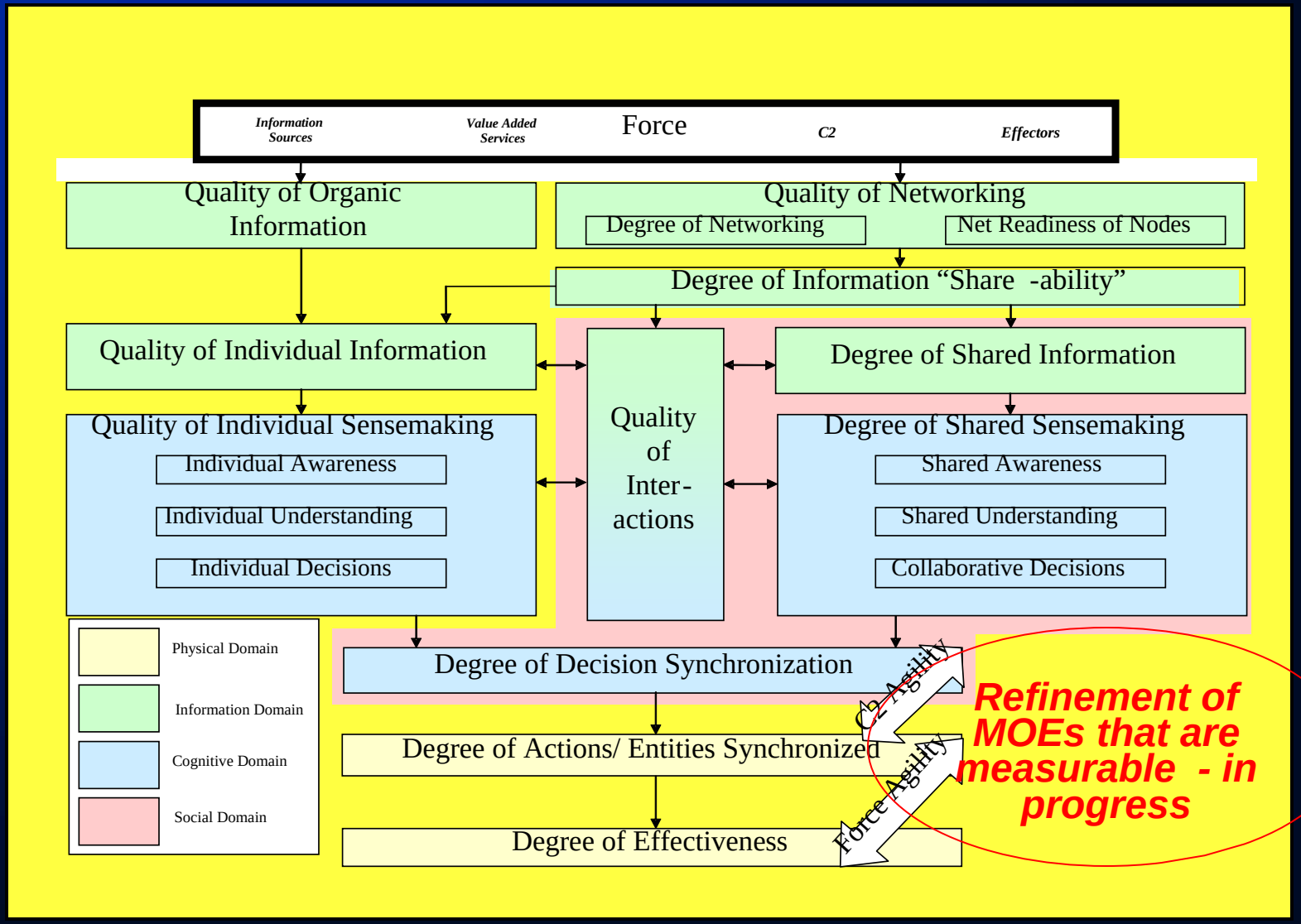
Measurement using the NOCF



[1]Net Centric Operations Conceptual Framework, Version 2, OSD/OFT/NII, June 2004

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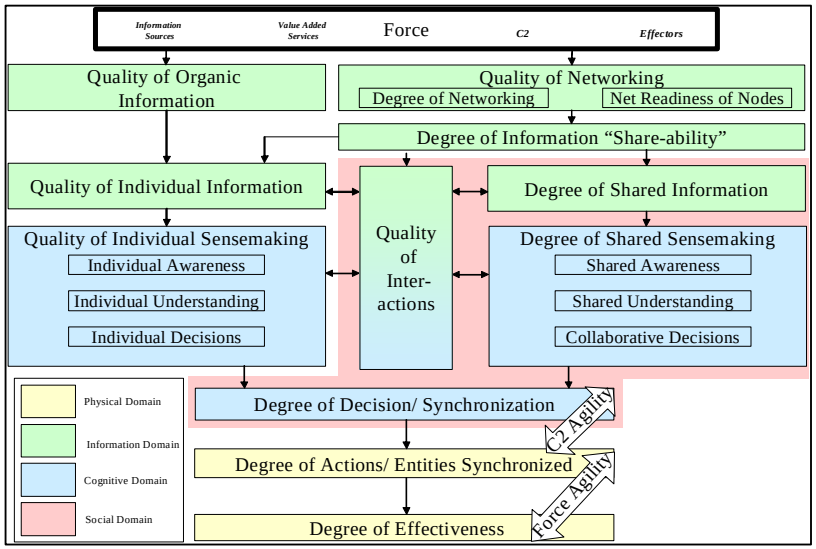
NCOF support to Future Capability Development

Past Investments

D O T M L P F

Assessment of How We Fight Today
(Based on Evidence & Analysis)



NCW Conceptual Framework

Informs

Future Investments

D O T M L P F

[1]Net Centric Operations Conceptual Framework, Version 2, OSD/OFT/NII, June 2004

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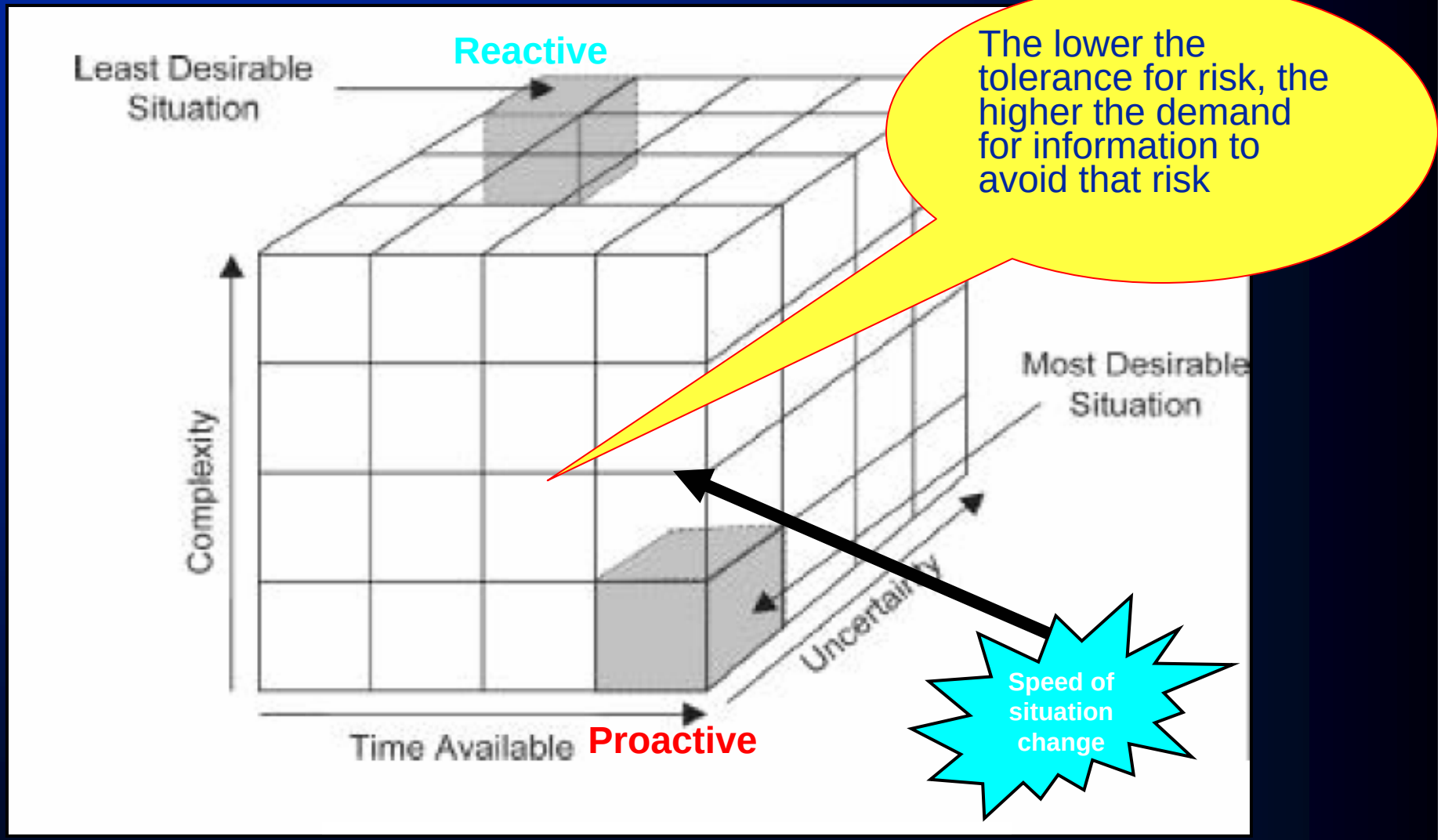
Drivers of Decision-making



[1] NATO Code of Best Practice for C² Assessment, CCRP, 2002

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Observations on Experimentation

Challenge of extracting meaningful data from experimentation with HITL:

- "Decision-making that is rule or algorithmically based can be modeled directly, but error rates should be estimated if humans are involved in the relevant decision-making
  - Implications for SE: FMEA of technology based on effects of the HITL on Mission success
- Operational knowledge of human issues is still weak in many areas [of C2]. Systematic effort is required for organizing a consistent program for experiments on human issues."[1]

[1] NATO Code of Best Practice for C² Assessment, CCRP, 2002

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Summary of Approaches for Engineering in the Cognitive and Social Domains

- **Observation and feedback**
  - Expensive if done late in development during prototyping
  - Needs to be done very early to minimize cost of development
- **Stimulus/response analysis**
  - Paper simulation
  - War gaming
    - Concept exploration with instrumentation
- **Isolation of components of cognitive domain and social domains**
  - Use NCOCF model attributes

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Summary

- We need to provide systems and services to our warfighters quickly, but not without understanding how they are used both cognitively and socially on the battlefield
- This is broader than the Human Computer Interface (HCI) used in systems engineering today
- Just as bio-engineering revolutionized medicine, Cognitive Engineering and HSI as key considerations in systems engineering are and will revolutionize the conduct of on both the strategic and tactical levels of warfare
- Resource to review Human Performance Engineering
  - ONR >>SC-21/ONR S&T Manning Affordability Initiative (FY96-FY00)
    - http://www.manningaffordability.com/s&tweb/index.htm

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Other Observations

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Humans and Complexity on the Network

- It has been noted[1] that good commanders have dealt with the complexities of the battlespace by inserting a "human in the loop"—whether themselves, subordinate commanders, staff, or watch personnel—to make complex decisions, to assess ambiguous information, and to fill in the blanks where information is wanting.
- The human is at the root of *network-enabled* effects-based operations.
- Whereas success in "classic" effects-based approaches largely depended on the abilities of the humans in the loop to deal with the complexity in their heads, in network-enabled operations they need no longer be left to their own devices.
  - Better and more meaningful support from networking can enable decision-makers to bound complexities and deal with ambiguities better and thereby increase the probability of a correct decision.

[1]Complexity, Networking and Effects Based Approaches to Operations, Edward A Smith, CCRP, 2006

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World War IV and implications for SE and the HITL

It was noted by *Maj. Gen. ROBERT H. SCALES (ret.)* that:

THE EVOLUTION OF WARFARE

THE CHEMISTS' WAR

The decisive strategic advantage on the World War I battlefield was driven by new applications of chemistry and chemical engineering. Germany, for example, exhausted its supplies of gunpowder nitrates in 1915, but the synthesis of nitrates by German scientists allowed the war to continue for another three years.

THE PHYSICISTS' WAR

The atomic bomb ended World War II, but exploitation of the electromagnetic spectrum in the form of wireless communications and radar won it for the allies.

THE INFORMATION RESEARCHERS' WAR

In World War III, intelligence and the ability to fully exploit it allowed the U.S. to defeat the Soviet Union. Information-age concepts of transformation and net-centrism mark the end of this epoch.

THE SOCIAL SCIENTISTS' WAR

To win World War IV, the military must be culturally knowledgeable enough to thrive in an alien environment. Victory will be defined more in terms of capturing the psycho-cultural rather than the geographical high ground. Understanding and empathy will be important weapons of war.

[1] ***Maj. Gen. ROBERT H. SCALES (ret.) , "Clausewitz and World War IV" , Armed Forces Journal, July 2006***

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Observations from Maj. Gen. ROBERT H. SCALES (ret.)

- "Machines and processes might make intelligence easier to parse and read. But knowing the enemy better than he knows us is inherently a psycho-cultural rather than a technological, organizational or procedural challenge."[1]
- "The enemy has drawn us unwillingly into fighting him at the tactical level of war where the importance of technology diminishes in proportion to the value of intangibles. "
- "Models of human cognition can also be used to diagnose performance failures during simulated exercises. "
- "We are in a race, and the times demand change. World War IV can only be won by harnessing the social and human sciences as the essential amplifiers of military performance, just as the physical sciences were the amplifiers of past world wars. "
- "Of course, new planes, ships and combat vehicles will have to be built to win World War IV, but building new social, cultural and learning structures will have to become the first priority for resources within the Defense Department. There is an old saying that the Navy and the Air Force man the equipment and the Army and Marine Corps equip the man. Surely those services that focus on the man rather than the machine should receive a disproportionate share of future defense budgets? "
- "What will the new amplifiers be? ….. Will new human and behavioral developments make us more effective in battle? Only time will tell. But none of these questions can be answered by speculation alone. The Defense Department must invest the resources now to realize the potential of psycho-cultural sciences to winning World War IV."

[1] *Maj. Gen. ROBERT H. SCALES (ret.) , "Clausewitz and World War IV" , Armed Forces Journal, July 2006*

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Implications of Agent Based-Simulation

- Agent =-based simulation (e.g., SEAS) now takes into account the Cognitive Domain (via Programmed behaviors - Behavioral and decision-making logic)
  - Good enough for SE trade studies?
  - Good enough to go operational?
  - How much can we trust the outcomes of these simulations where 100s (if not 1000s) of entities interact to end in an effect

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Beyond the OODA[1] loop

- OODA is the foundation for understanding Effects-Based Operations
- OODA has different implications at the strategic and tactical levels
- How do we engineer a capability to improve the OODA without considering the HITL?
- Clearly, the cognitive processes that allow the human to perceive and decide are at the center of the human dimensions of war
- Capabilities are written in terms of what the human needs to accomplish , not what the machine must do

[1]OODA: observe, orient, decide, act

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