15th ICCRTS

"THE EVOLUTION OF C2"

Technical and Scientific Architecture For Testing and Evaluating Net-Centric Ecosystem

Suggested Topics: Experimentation and Analysis; Modeling and Simulation; C2 Architectures and Technologies

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EXPERT: AGILE CAN HELP THE DOD SAVE ITS PROJECTS

The U.S. Department of Defense has spent 10 years and more than US$100 billion to develop a "netcentric" capability—the notion of effective distributed collaborative processes around information processing, and its efforts have been largely unsuccessful. The solution—adopting more agile, collaborative processes—could apply to any large organization, said Chris Gunderson, research associate professor of information science at the Naval Postgraduate School.

The DoD has very little to show for its efforts due to an over-reliance on waterfall methodology, as well as a bureaucratic firewall between government and industry experts, said Gunderson. "Waterfall is appropriate for building nuclear missiles, but it can't be used to build everything. With those parallel problems, it's too ponderous a process to succeed," he said.

"The only success cases for distributed processing ride on top of the Web," he said, adding that eBay, FedEx and Google are successful examples.

The military has been discovering what processes work in the world of the Internet (collaborative, business processes, and open source), why they work, when they work, and how they scale, Gunderson said. But a "clumsy government acquisition process" gets in the way when it tries to co-opt those processes.

When the DoD attempted to transform itself into a network-centric enterprise, "two worlds were colliding," he explained. "It is delivering information processing capability like people built battleships in the old days."

Chris Gunderson says that waterfall development does not work for all projects.

Concepts such as open module design, spiral development and other commercial best practices don't scale inside the "metaphorical firewall" of the DoD system, Gunderson explained. He said that the private sector success cases were "predicated on massive economy of scale, reuse of components, and competition in the field."

They also met the requirements of end users. Given the constraints the military operates under, "My community advocates that agile is only way to go," Gunderson said.

However, there has been some progress in creating new government systems outside the confines of the DoD's rules and regulations, Gunderson said.

The government had an "odd success" in the creation of the IRS e-file system, by introducing open-source intellectual property to the financial community and by creating a commercial ecosystem, Gunderson said. "It also mitigated the commercial risk by providing a governance and certification model—the parameters of a level playing field."

The National Weather Service is another success case. When the Weather Service began giving away the results of its weather research, it worked on commercial standards for capturing and exploiting data, he said. "There is now a robust community of value-added weather services. The [return on investment] is obvious." ▯

—*David Worthington*

SD Times, Page 5, November 1, 2009

"(t)he development of the Army's Future Combat Systems (FCS) is experiencing cost and schedule overruns because of the *immense complexity* *of the effort (Weiner, 2005). Given the committee's findings about the immaturity of Network Science, this is hardly surprising. Designing and testing the FCS communications network alone is like trying to design and test a modern jet aircraft without the benefit of the science of aerodynamics or like designing and testing a radio or TV without the benefit of the fundamental knowledge of electromagnetic waves…*

The engineering of complex physical networks, like that of the FCS, is not predictable because the scientific basis for constructing and evaluating such designs is immature."
[**NRC ON NCO REPORT TO ARMY, 2005**]

Birth of Net-Centricity

Alberts et al. [Alberts et al. 1999] define Net-Centricity as follows:

"*Net-Centricity is an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization.*

In essence, (Net-Centricity) translates information superiority into combat power by effectively linking knowledgeable entities in the battlespace."

Why Has the DoD Failed To Successfully Implement Net-Centricity For 11 Plus Years?

- ???
- Without Net-Centricity, No Information Age Enterprise (Edge Enterprise) Can occur
- No Information Age Enterprise (Edge Enterprise) Implies No GIG (Global Information Grid)
- How do you integrate Tribal Leaders and Local Tribesmen (who naturally form Edge Based Organizations) in Afghanistan into an adaptive complex SoS without a GIG (Global Information Grid)?
- So, what is the solution?

OVERVIEW OF PRESENTATION

- Discuss NRC Report's to the Army on Net-Centric Operations & Author's Previous Work
- Discuss Principles of Power to the Edge
- Emphasize Importance of *Power to the Edge:*
  - Could Be Applied to Not Only Design and Architecture of Systems, Such As Net-centric Enterprise, but Also for Testing and Evaluating Any Large-scale Systems-of-Systems (SoS)
- Complexity Theory Proposed By Moffat
- Carley's Work at CMU (Carnegie-Mellon University)
- Discuss ITEA efforts in Net-Centricity
- Borrow from Author's Previous Work To Establish the technical and scientific foundation for large-scale SoS design and evaluation, followed by a discussion of a generic hypothetical technical and scientific architecture for designing, testing and evaluating the Net-Centric Ecosystem.
- New Paradigm For Designing, Testing and Evaluating Net-Centric Ecosystem.
- Conclusions

PREVIOUS WORK

- Only One or Two Technical Publications In the Literature Address:
  - technical and scientific architecture for testing and evaluating Net-Centric Ecosystem or complex large-scale systems-of-systems (SoS)
- Army’s National Research Council Report on NCO
- Author’s Previous Work

Army's NRC Report [NRC 2005]

Though the NRC did not specifically mention the term "test and evaluation," their report indirectly implies such a missing gap. They classified all complex large-scale SoS, for example the FCS, under a new scientific discipline known as "Network Science." <u>According to NRC we know a lot about the design, construction, and use of the components of physical networks</u>. <u>However, the science of integrating these components into large, complex, interacting networks, for example the Global Information Grid (GIG), that are robust and whose behaviors are predictable is uncharted ground</u>. For example, communications networks that are being built today exhibit unpredictable behavior and robustness.

Army’s NRC Report [NRC 2005] Cont’d

For example, communications networks that are being built today exhibit unpredictable behavior and robustness. Without first testing and evaluating the individual components and retesting and reevaluating the integrated SoS when the networks of individual components interact with each, we cannot achieve robustness of such complex large-scale SoS. <u>The NRC strongly emphasized that the development of predictive models of the behavior of large complex networks is difficult and without a strong scientific basis for constructing and evaluating such designs, achieving the tenets of Net-Centric Operations would be extremely difficult</u> [NRC 2005].

Nyamekye’s Recent Work [June 2010]

- His Work Was Based on Importance of Power to The Edge and Axiomatic Design for Testing & Evaluation:
  - *Power to the Edge* concepts that say that we should first establish <u>Architecture Design And Systems before we can proceed with Command and Control (C2) and more importantly, the Campaigns of Experimentation, which involves test and evaluation of complex endeavors</u> [Alberts et al. 2007].

Nyamekye's Recent Work [June 2010] Cont'd

- Nyamekye did not discuss any architecture, which establishes the scientific basis for designing, testing and evaluating any complex large-scale systems. Of particular importance is how we test and evaluate the cognitive and social behaviors of participants with diverse cultural backgrounds, typical in counterinsurgency operations and especially in humanitarian efforts during natural disasters. We should emphasize that the cognitive and social behaviors exist in cognitive and social domains in any enterprise, respectively.

Power to the Edge, Across The Four Domains

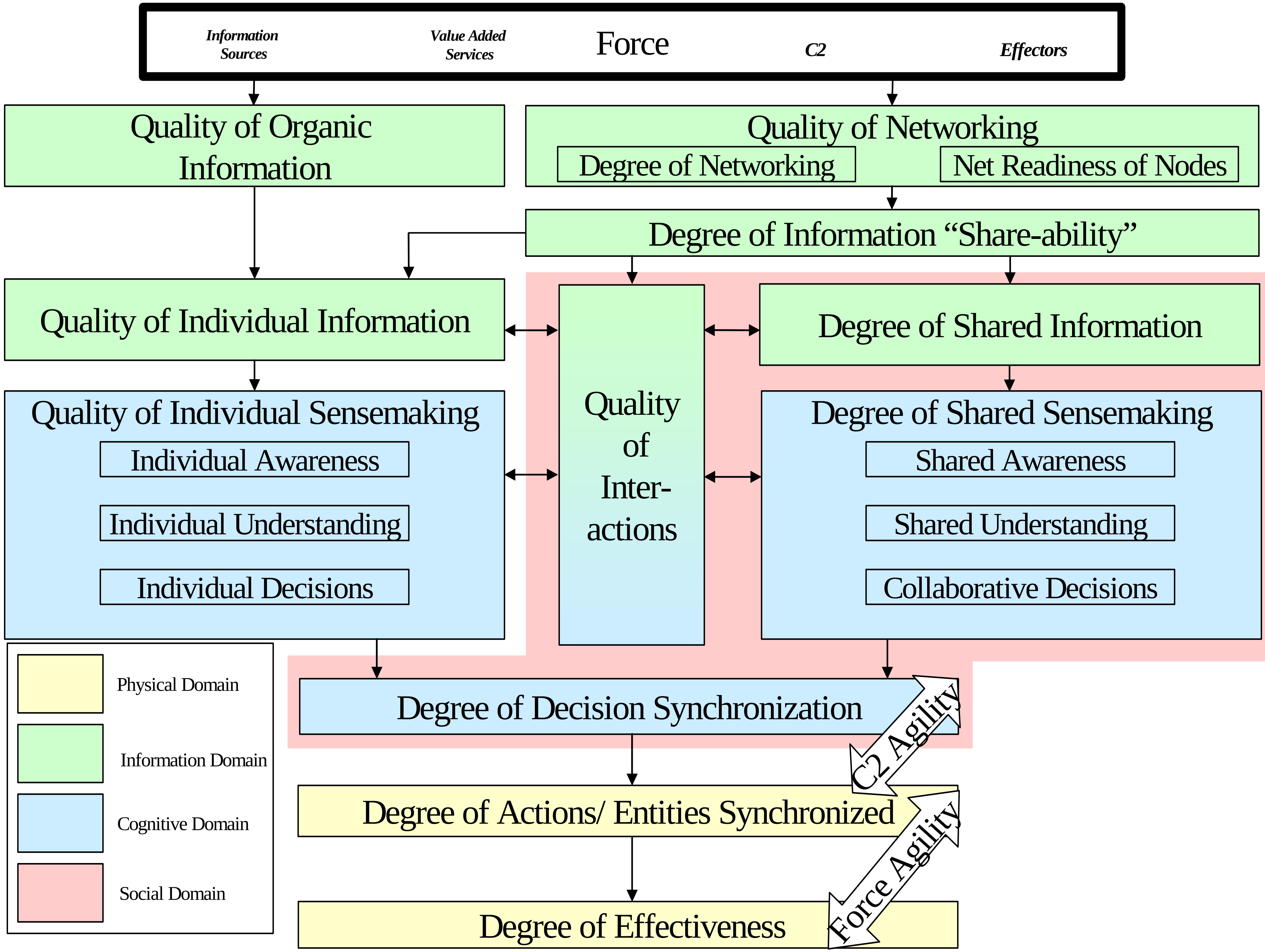
- Design and architecture of systems-of-systems -- infostructure -- relate to the physical and information domains. The C2 sensors, systems-of-systems, platforms, and facilities exist in the physical domain. The information collected, posted, pulled, displayed, processed, and stored exists in the information domain.

- C2 (or organization and management of work) relates primarily to cognitive and social domains. The perceptions and understanding of what this information states and means exist in the cognitive domain. Also in the cognitive domain are the mental models, preconceptions, biases, and values that serve to influence how information is interpreted and understood, as well as the nature of the responses that may be considered. Interactions between and among individuals and entities that fundamentally define organization and doctrine exist in the social domain.

Power to the Edge Applies To Testing & Evaluation

- Though test and evaluation are not directly mentioned in the *Power to the Edge*, it is quite clear from Alberts et al.'s work [Alberts et al. 2003] that we must address these domains when designing, testing and evaluating each component. For example, a futuristic net-centric platform, which operates in a futuristic DoD Edge-Based Organization, must not only be tested and evaluated as an autonomous unit in the physical and information domains but also it must be tested and evaluated in actual interactions with other components in the social domain in a Net-Centric Ecosystem, to achieve the global behavior of a given mission.

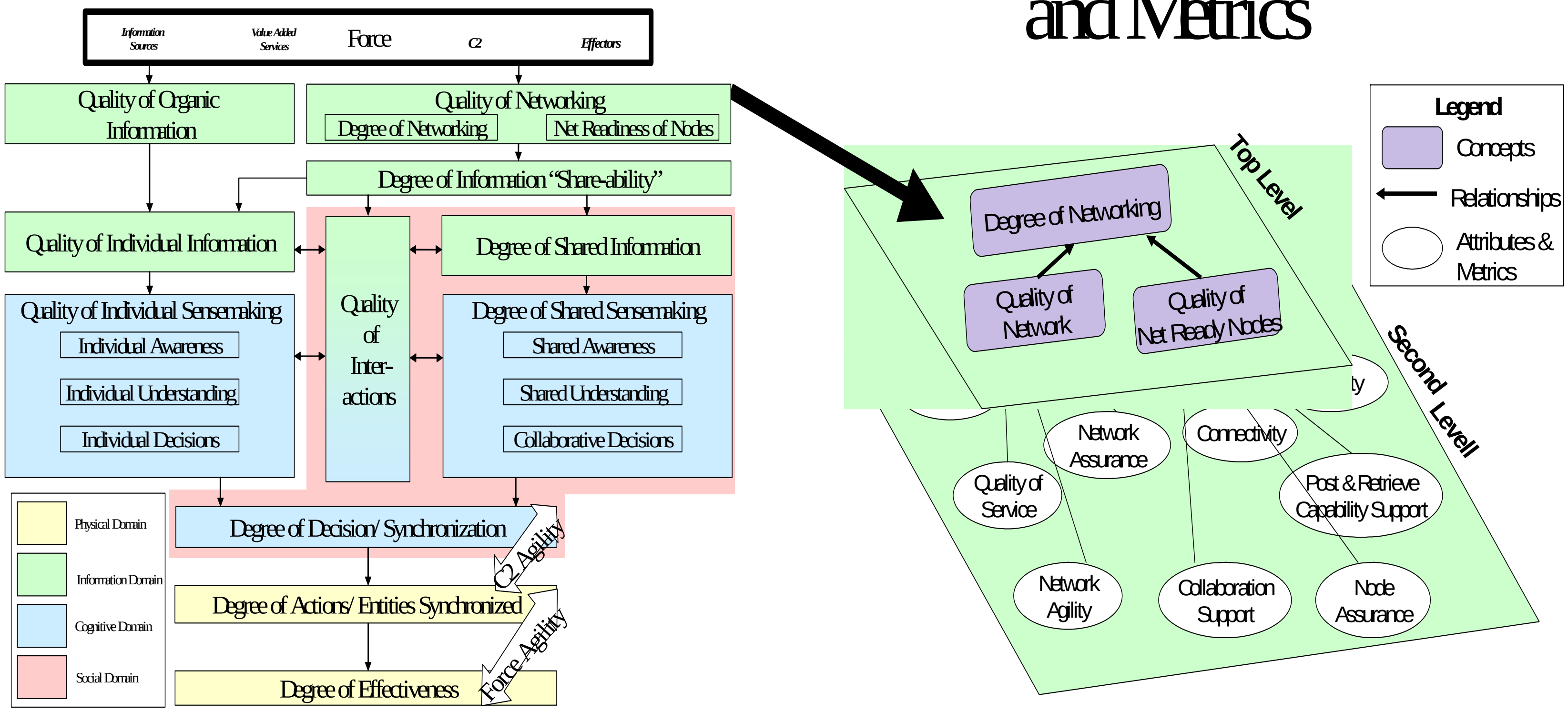
- When we test and evaluate the perceptions and understandings of individuals as autonomous units, we are essentially doing so in the cognitive domain. Thus, any technical and scientific architecture for test and evaluation should embody the principles of the *Power to the Edge*.



Information Sources
Value Added Services
Force
C2
Effectors
Quality of Organic Information
Quality of Networking
Degree of Networking
Net Readiness of Nodes
Degree of Information "Share-ability"
Quality of Individual Information
Quality of Interactions
Degree of Shared Information
Quality of Individual Sensemaking
Individual Awareness
Individual Understanding
Individual Decisions
Degree of Shared Sensemaking
Shared Awareness
Shared Understanding
Collaborative Decisions
Degree of Decision Synchronization
C2 Agility
Degree of Actions/ Entities Synchronized
Force Agility
Degree of Effectiveness
Physical Domain
Information Domain
Cognitive Domain
Social Domain

Top Level Concepts

Second Level Attributes and Metrics



Each Concept in the Top Level is Mapped to Second Level Attributes and Metrics

Moffat’s Work

- Moffat discussed experimental mathematics as a way to analyze the co-evolution of complex adaptive systems, such as the DoD Net-Centric Enterprise and its supporting infostructure -- GIG [Moffat 2003]. He considered an ecosystem consisting of a large number of interacting species (such as the force elements at the grid points in GIG), each evolving in response to the environment created by the rest of the ecosystem (that is, each species is *coevolving*) [Moffat 2003]. Such a system consists of many components that interact through some kind of exchange of forces or information [Moffat 2003]. In addition to the internal interactions, some external force -- natural selection -- may drive the system in this case.

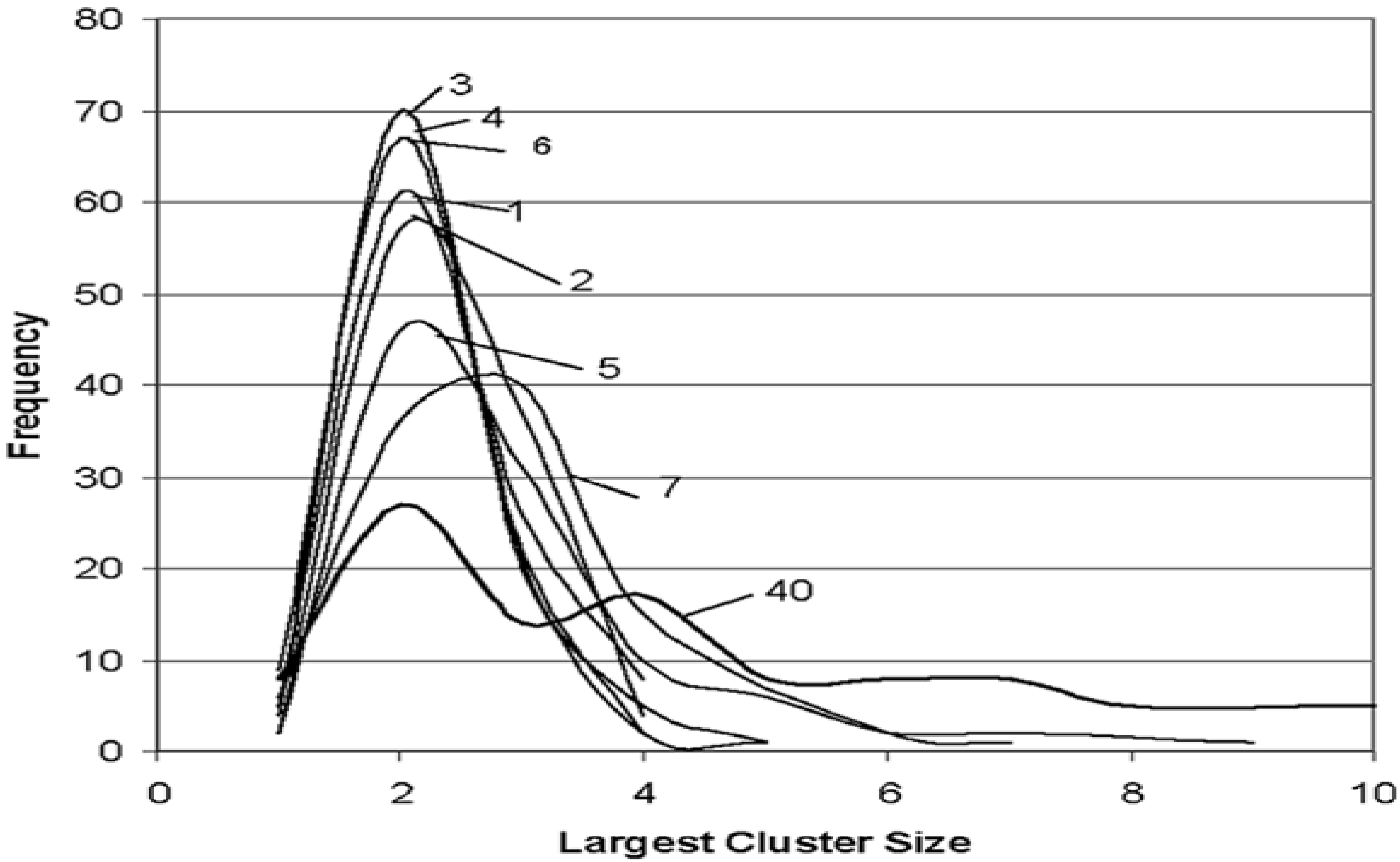
- The system will now evolve over time under the influence of the external driving forces and the internal interactions. The questions Moffat was trying to answer were as follows. *What happens when we observe such a system* [Moffat 2003]? *Is there some simplifying mechanism that produces a typical behavior shared by large classes of such systems* [Moffat 2003]?

Moffat's Work (Cont'd)

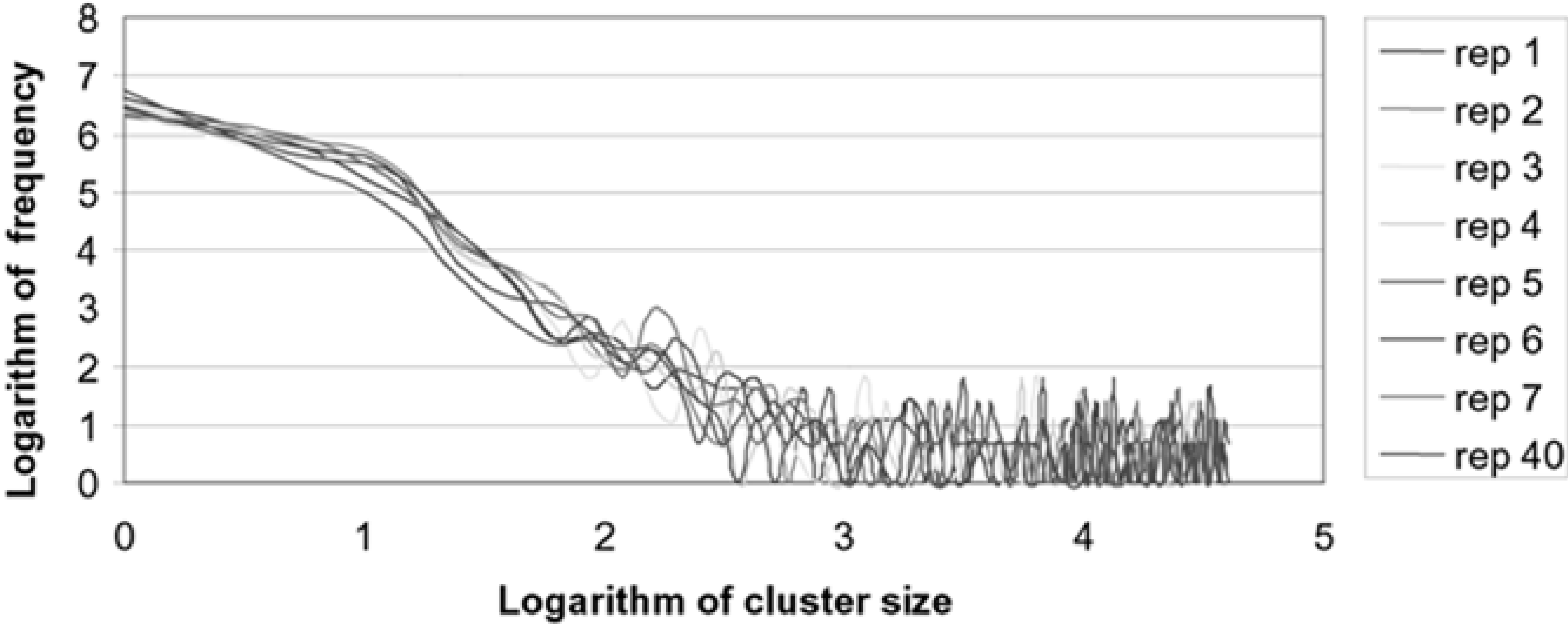
- He established that *clustering* was the mechanism. He found that as the species interact, they co-evolve into clusters and when the cluster size reaches a critical value or natural fitness value, the system would have optimal flexibility. That is, clusters of all sizes can be created. The physical implication is that the ecosystem can achieve infinite agility, which is one of the major requirements of the force structure for Net-Centric Warfare (NCW) and more importantly futuristic Net-Centric platforms for counterinsurgency operations.

- Furthermore, at the critical fitness value, the species interact to achieve the global behavior of the entire ecosystem. More importantly, he established that we could use the power-law function (or exponential density function) to ***evaluate the performance*** of such a force structure. Despite his visionary work, he did not explain how we could adapt it to design, test and evaluate the Net-Centric Enterprise, for example how we design, test and evaluate the GIG network to adapt itself to uncertainties such as cyber attack, on the battlefield. Axiomatic Design fulfills the deficiencies of Moffat's work.

Moffat's Work (Cont'd)



Moffat's Work (Cont'd)



International Test and Evaluation Association (ITEA Approach To Net-Centricity

- Testing in Service Oriented Architectures (SOA)
- Sensor to shooter testing
- The use of modeling and simulation in network centric testing
- The implications for testing against cyber threats

Carley’s Work at CMU

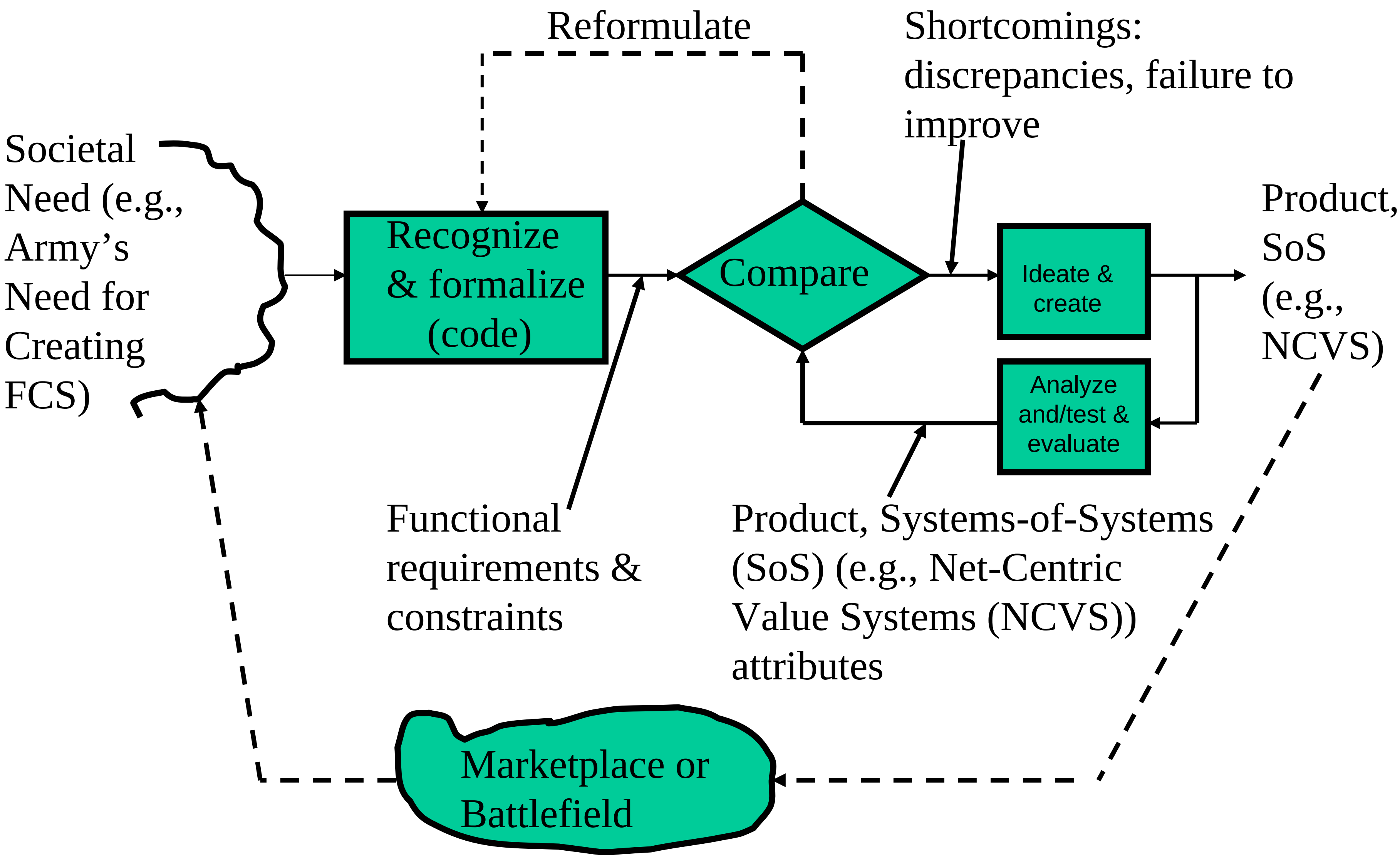
	People	Knowledge	Resources	Tasks/Projects
People	Social Network *Who talks to, works with, and reports to whom*	Knowledge Network *Who knows what, has what expertise or skills*	Resource Network *Who has access to or can use which resource*	Assignment Network *Who is assigned to which task or project, who does what*
Knowledge		Information Network *Connections among types of knowledge, mental models*	Resource Usage Requirements *What type of knowledge is needed to use that resource*	Knowledge Requirements *What type of knowledge is needed for that task or project*
Resources			Inter-operability and Co-usage Requirements *Connections among resources, substitutions*	Resource Requirements *What type of resources are needed for that task or project*
Tasks/ Projects				Precedence and Dependencies *Which tasks are related to which*

Details of Carley's Work

- She modeled an organization as a set of interlocked networks connecting entities such as people, knowledge resources, tasks and groups. We can represent these interlocked networks using meta-matrix conceptual framework, Table 1. Carley defined meta-matrix as a conceptual description of an organization and as an ontology for characterizing key organizational entities and the relations among them.

- She established several metrics for evaluating the performance of the agents. Among the metrics is cognitive demand, which measures the total amount of cognitive effort expended by each agent to its tasks. Her work is very intriguing because we can use it to measure the cognitive demand of warfighters on the battlefield. The results could then help the commanders and the warfighters on the battlefield to determine the effect of such a metric and other metrics on the success or failure of mission outcomes and the remedial actions to ensure a mission success, before actual execution of combat operations. More importantly, if we can build a hybrid-model consisting of Carley's work, agent-based modeling and simulation (ABMS), and Service Oriented-Architecture (SOA)-Based Cloud Computing Model [Nyamekye June 2010], we can achieve a promising future to designing a technical and scientific architecture for testing and evaluating Net-Centric Ecosystem.

DESIGN & TEST OF COMPLEX SYSTEM



The Design Loop-As the Architecture for Systems-of-Systems [Nyamekye 2007; Wilson, D. R., Ph.D. Thesis, MIT, August, 1980]

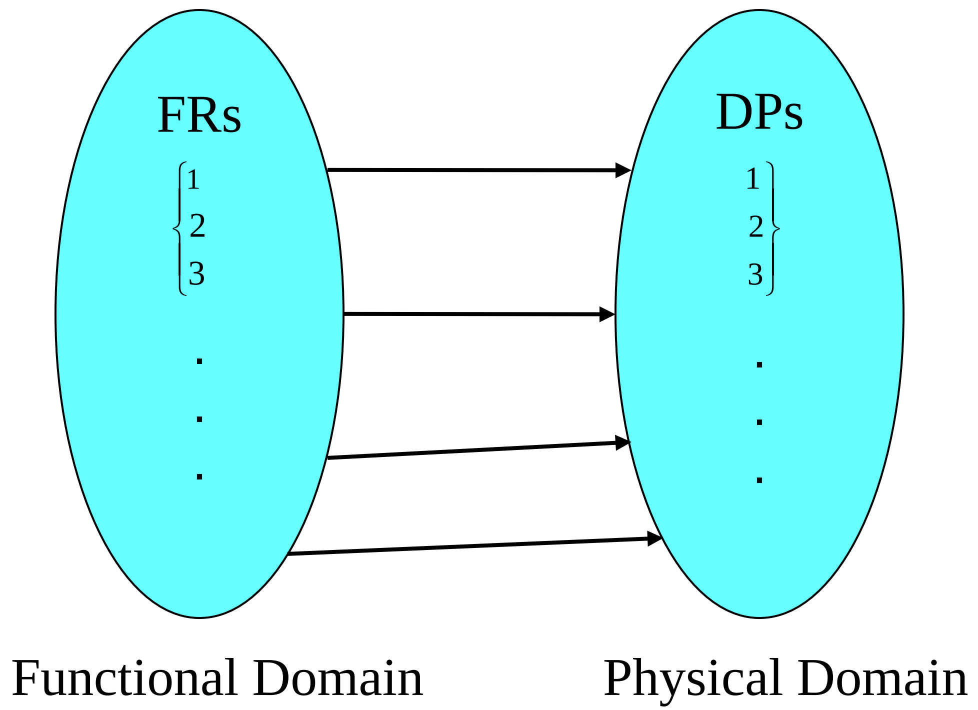
BRIEF OVERVIEW OF AXIOMATIC DESIGN– SUH FROM MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT)

TWO AXIOMS:

AXIOM 1: In a good design, the independence of functional requirements (FRs) is maintained.

AXIOM 2: The design that has the minimum information content is the optimal design.

In addition to the functional requirements, a set of constraints may also exist. On the battlefield, how much collateral damage, and how many casualties are "acceptable" in a theater operation, could represent the constraints [Alberts et al. 2003].



Mapping from the Functional Domain (or Space) to the Physical Domain [Nyamekye 2007; Suh 1990]

In addition to AXIOM 1 and AXIOM 2, the following four corollaries and two theorems, are essential for designing NCE, namely [Suh 1990; Suh 2001]:

Corollary 1: Decoupling of Coupled Design: Decouple or separate parts or aspects of a solution if FRs are coupled or become interdependent in the proposed designs.

Corollary 2: Minimization of FRs: Minimize the number of functional requirements and constraints. Strive for maximum simplicity in overall design or the utmost simplicity in physical and functional characteristics.

Corollary 3: Integration of Physical Parts: Integrate design features into a single physical process, device, or system when FRs can be independently satisfied in the proposed solution.

Corollary 4: Use of Standardization: Use standardized or interchangeable parts, architecture, process, device, or system if the use of these parts, architecture, process, device, scientific concept, or system is consistent with the FRs and constraints. This corollary establishes the <u>governance model</u> for designing any large-scale SoS.

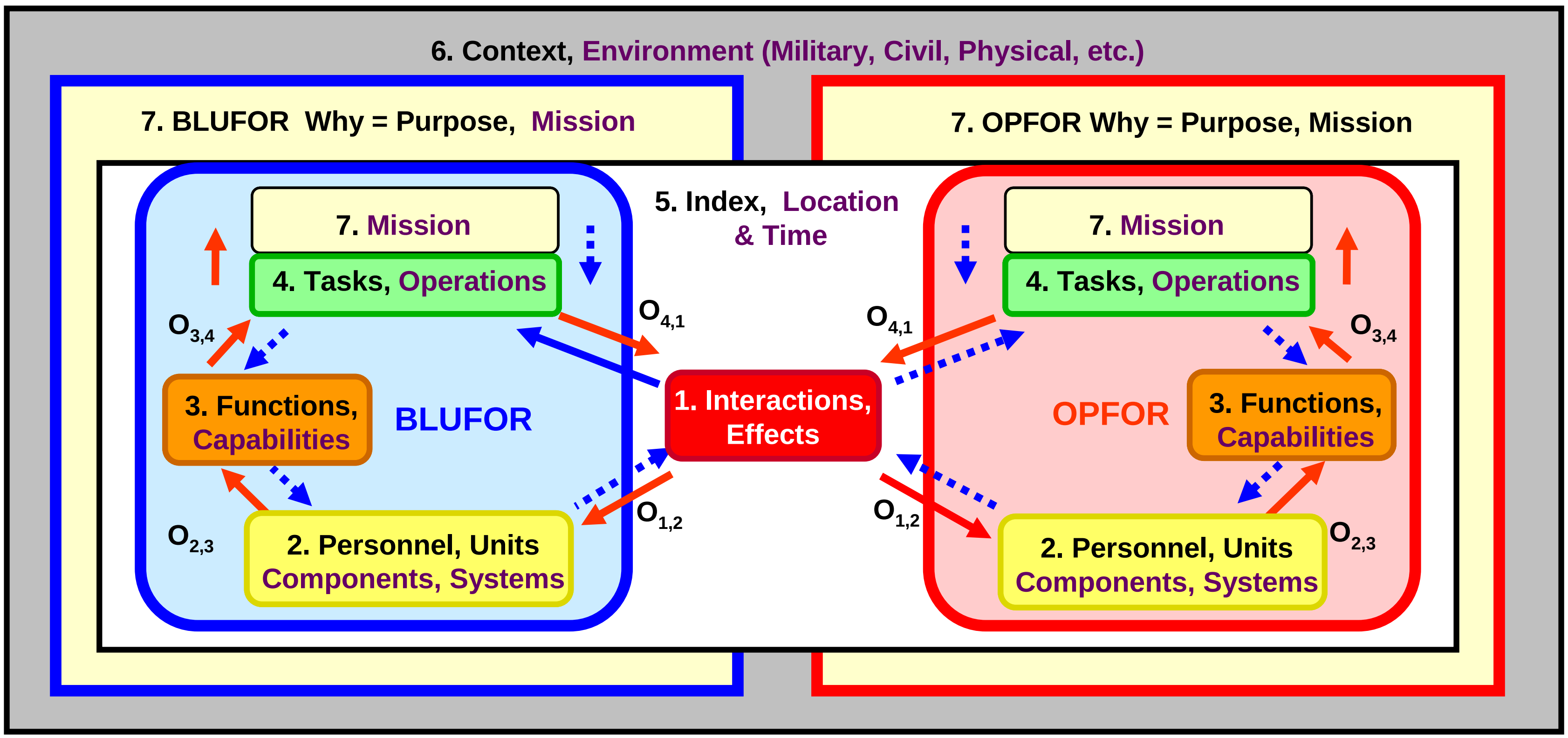
THEOREM M2 (Large System with Several Subunits) ***When a large (e.g., organization) consists of several subunits, each unit must satisfy independent subsets of FRs so as to eliminate the possibility of creating a resource-intensive system or a coupled design for the entire system.***

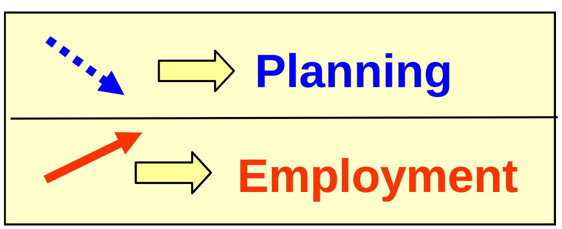
THEOREM S7 (Infinite Adaptability versus Completeness) ***A large flexible system with infinite (adaptability) may not represent the best design when the large system is used in a situation in which the complete set of FRs that the system must satisfy is known in priori.***

Missions and Means Framework

[Deitz et al. 2003; Minchew 2006.]

11 Fundamental Elements: 7 levels, 4 operators





Developed by Dr. Paul Deitz, Technical Director, US Army Material Systems Analysis Activity and Mr. Jack Sheehan, Chief Engineer, Future Combat Systems, Combined Test Organization

Parts Taxonomies

Packages Networks

Axiomatic Design (AXIOM 1) for Specifying Complexity Equations for MMF Ontology:

FR_1 \$ $(DP^a{}_1, DP^b{}_1, DP^c{}_1 \ldots\ldots\ DP^r{}_1)$ Equation 1

Similarly, the equations for other FR_s can be structured as follows:

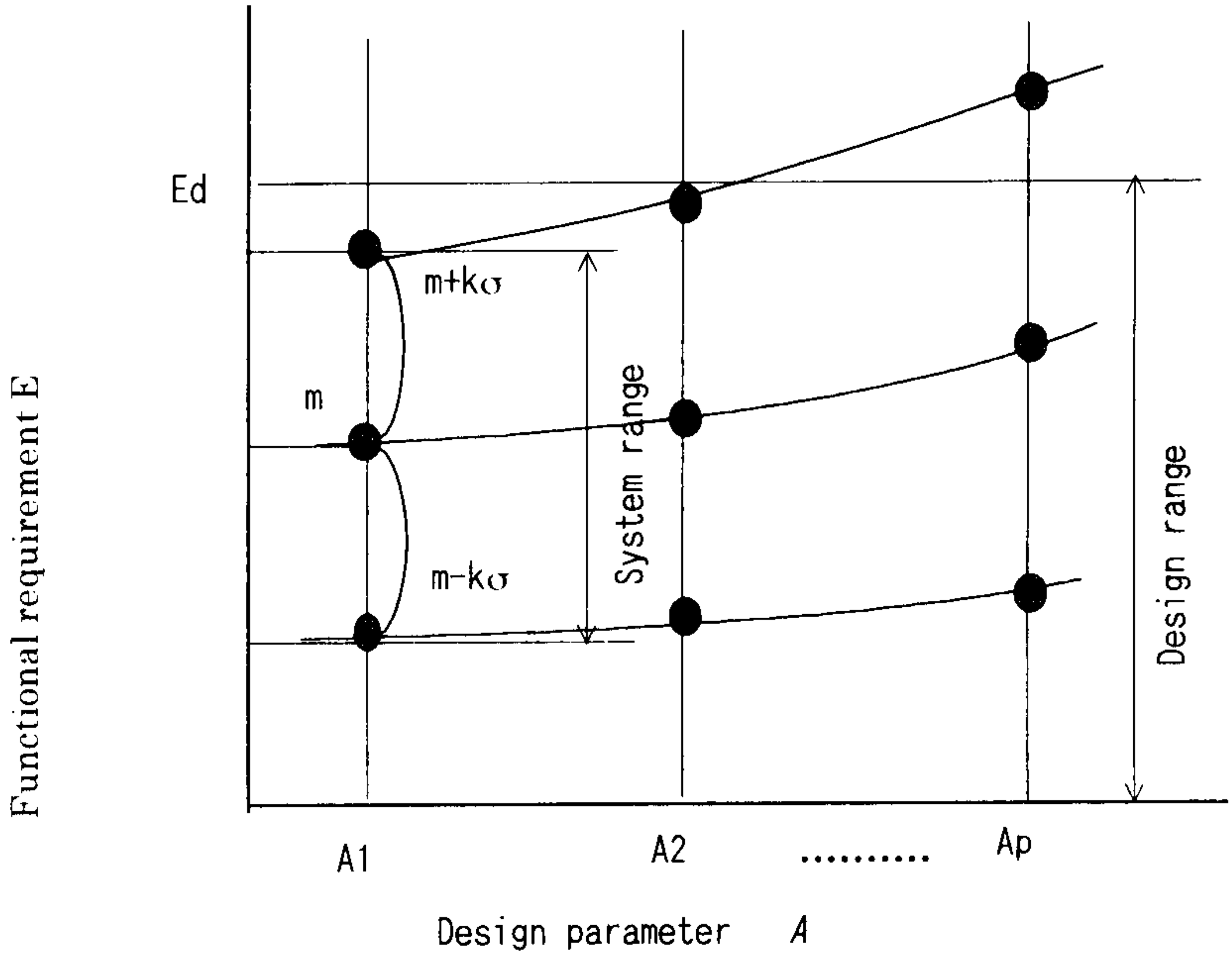
FR_2 \$ $(DP^a{}_2, DP^b{}_2, DP^c{}_2 \ldots\ldots\ DP^q{}_2)$

FR_3 \$ $(DP^a{}_3, DP^b{}_3, DP^c{}_3 \ldots\ldots\ DP^w{}_3)$

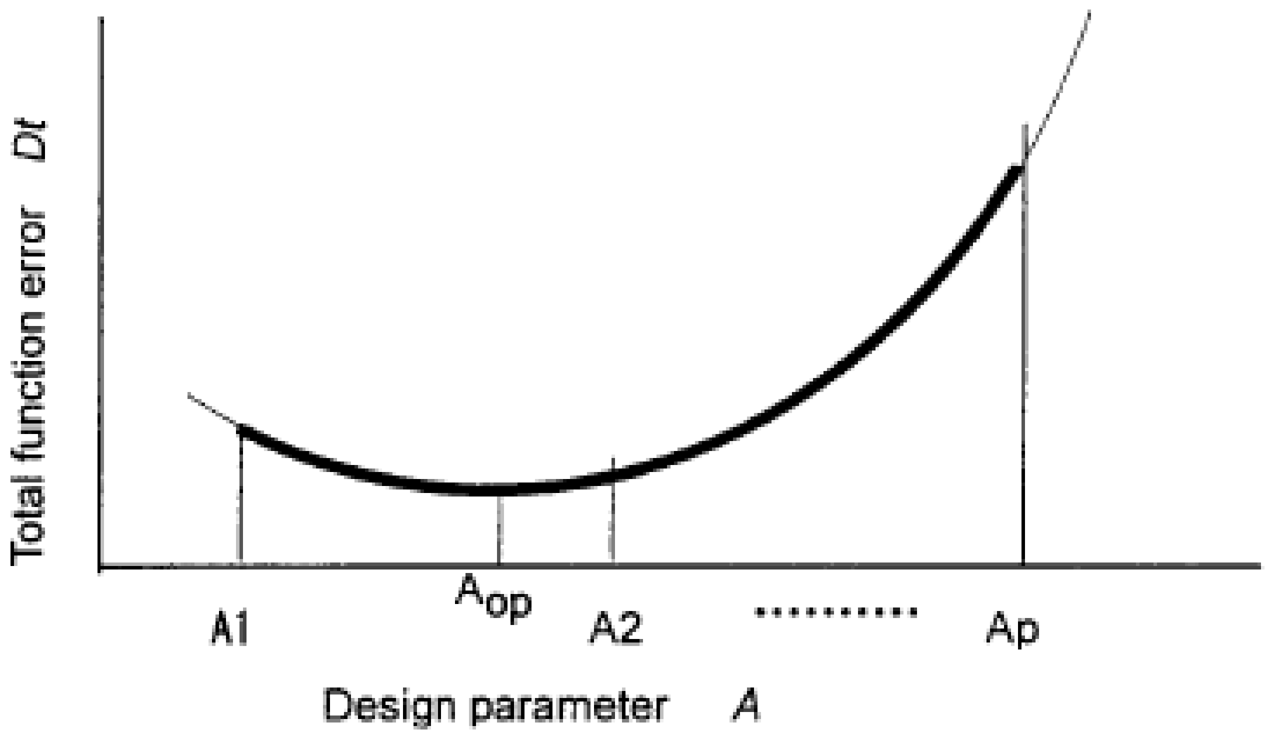
….

FR_m \$ $(DP^a{}_m, DP^b{}_m, DP^c{}_m \ldots\ldots DP^s{}_m)$ Equation 2

Equation 1 simply states that FR_1, for example a mission task, can be satisfied (indicated by \$) by selecting $DP^a{}_1$, $DP^b{}_1$, $DP^c{}_1$, etc. The $DP^a{}_1$ can represent for example, "Operations Package 1," from the knowledge base. Similarly, FR_m, satisfied by selecting $DP^a{}_m$, $DP^b{}_m$, etc. The $DP^a{}_m$, can represent for example, "Capability Package m", from the knowledge base (in Compendium). AXIOM 2: OPTIMIZATION -- **FOR ANY GIVEN MISSION TASK(S) WHICH RESOURCES CAN EXECUTE THE TASKS TO ACHIEVE MOST FAVORABLE MISSION OUTCOMES?**



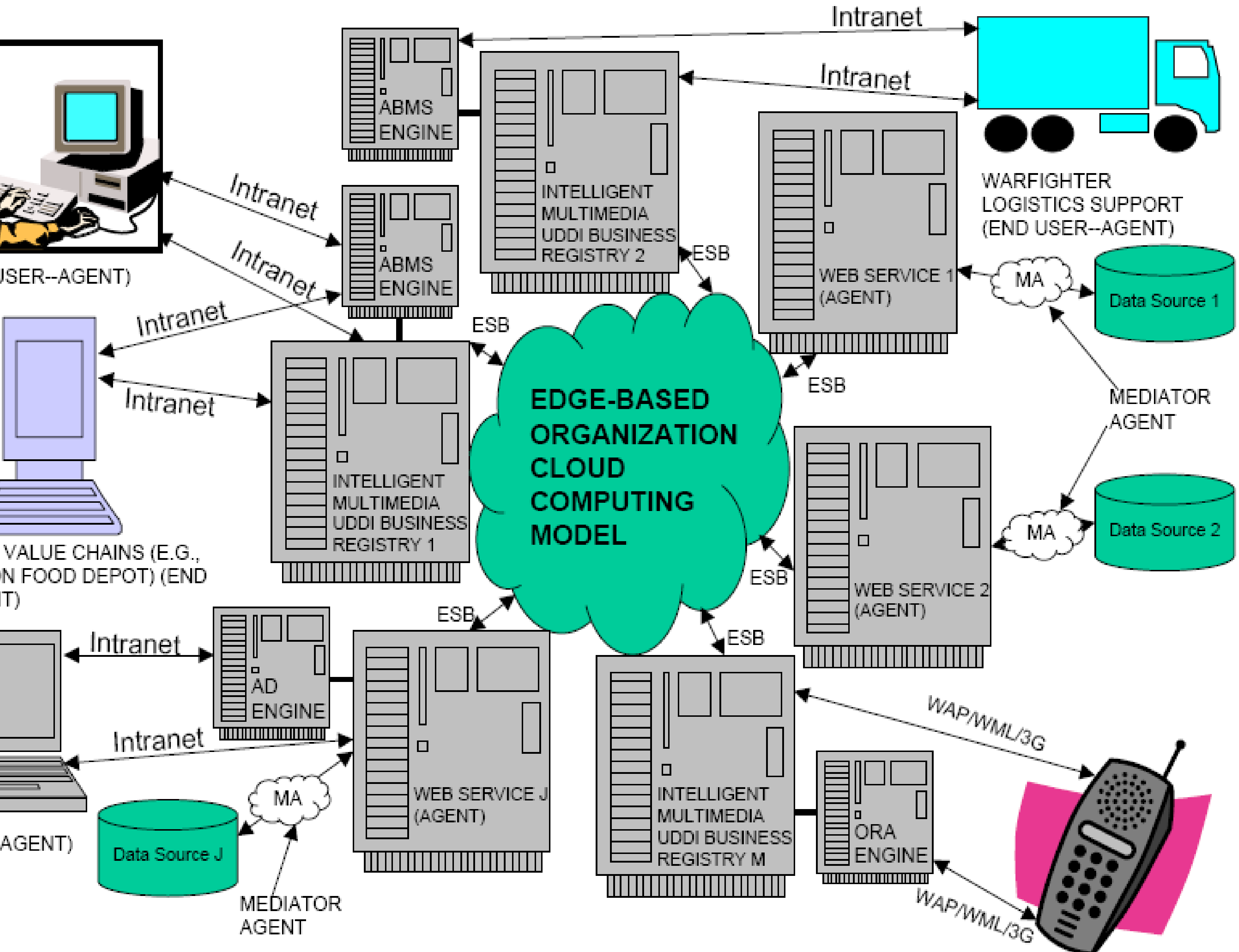
System Range of Design Parameter A for Functional Requirement E [Nakazawa 2001].



Total Information Content (Function Error Curve) [Nakazawa 2001].

NO	DESIGN PARAMETERS (DPs)				EXPERIMENTAL OR SIMULATION RESULTS FOR FUNCTIONAL REQUIREMENTS (FRs)		
	A	B	C	D	E	F	G
1	A1	B1	C1	D1	E1	F1	G1
2	A1	B2	C2	D2	E2	F2	G2
3	A1	B3	C3	D3	E3	F3	G3
4	A2	B1	C1	D1	E1	F1	G1
5	A2	B2	C2	D2	E2	F2	G2
6	A2	B3	C3	D3	E3	F3	G3
7	A3	B1	C1	D1	E1	F1	G1
8	A3	B2	C2	D2	E2	F2	G2
9	A3	B3	C3	D3	E3	F3	G3

Table 1. Orthogonal Table For Experimental Design for Evaluating the Collaborative Planning [Nakazawa 2001]. The functional requirements (FRs) correspond to measures-of-merit (MoM) or measures-of-effectiveness (MoEs).



Intranet
Intranet
ABMS ENGINE
INTELLIGENT MULTIMEDIA UDDI BUSINESS REGISTRY 2
WARFIGHTER LOGISTICS SUPPORT (END USER--AGENT)
Intranet
Intranet
ABMS ENGINE
USER--AGENT)
ESB
WEB SERVICE 1 (AGENT)
MA
Data Source 1
Intranet
ESB
ESB
Intranet
EDGE-BASED ORGANIZATION CLOUD COMPUTING MODEL
MEDIATOR AGENT
INTELLIGENT MULTIMEDIA UDDI BUSINESS REGISTRY 1
MA
Data Source 2
VALUE CHAINS (E.G.,
N FOOD DEPOT) (END
IT)
ESB
WEB SERVICE 2 (AGENT)
ESB
ESB
Intranet
AD ENGINE
WAP/WML/3G
Intranet
WEB SERVICE J (AGENT)
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E NEW PARADIGM FOR DESIGNING, TESTING D EVALUATING THE NET-CENTRIC

OSYSTEM

-CENTRIC ECOSYSTEM = MMF + AXIOMATIC DESIGN + ABMS + T & E

CONCLUSIONS

aper establishes technical and scientific architecture for testing and evaluating et-centric Ecosystem. Borrowing from the *Power to the Edge* concepts, the discusses the four domains of the Net-Centric Enterprise. The paper then asizes that though ***test and evaluation*** are not directly mentioned in the *r to the Edge*, it is quite evident from Alberts al.'s work that we must address ur domains when ***designing, testing and evaluating*** each component. Using a d-model of Carley's work, Axiomatic Design, MMF, agent-based modeling imulation (ABMS), and Service Oriented-Architecture (SOA)-Based Cloud puting Model, the paper then discusses in detail hypothetical architecture for ishing the technical and scientific basis for testing and evaluating Net-Centric ystem.

her major finding is that we can use Missions and Means Framework model ot only planning and execution of a DoD mission but also we can use it for ***ning, testing and evaluating*** the Net-Centric Ecosystem. This finding is icant because recent publication suggests that despite the significant amount ney spent by the DoD to develop a "net-centric" capability, the DoD has been

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