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Modeling the Construction of Actionable Knowledge within an Effects-Based Targeting Process

Dr. Dennis K. Leedom
Evidence Based Research, Inc.
1595 Spring Hill Road Suite 250
Vienna, VA 22182

DLeedom@ebrinc.com

Dr. Robert G. Eggleston
US Air Force Research Laboratory
AFRL/HECS
Wright-Patterson AFB, OH 45433

Robert.Eggleston@wpafb.af.mil

ABSTRACT

This paper presents an overview of the modeling issues relevant to portraying the construction of actionable knowledge within an effects-based targeting process. At the heart of these issues is the need to consider the various political, military, economic, social, information, and infrastructure dimensions that characterize a future coalition operation against a fourth-generation adversary. This type of warfare reflects a wicked problem space in which a major challenge for any command, control, intelligence, surveillance, and reconnaissance (C2ISR) system will be the proper framing of actions within this multi-dimensional battlespace. Described within the paper are a number of modeling issues addressed in current research by the authors: (1) the abstract decomposition of command intent objectives into key centers of gravity, functional elements that support these centers of gravity, and the battlespace nodes that comprise each functional element; (2) the representation of a data/frame model of sensemaking by means of a Leontief input-output matrix that allows the modeler to approximate each actor's tacit knowledge; (3) the explicit portrayal of collaboration within a C2ISR organization that reflects how the tacit knowledge matrices of different actors can be used in combination; (4) the consideration of a variety of collaboration obstacles—technological, cognitive, social, and organizational—that influence the process by which the C2ISR identifies, links, and facilitates specific sets of actors to represent different stakeholders and areas of expertise; and (5) the assessment of C2ISR system performance in terms of the degree to which the planned targeting actions achieves overall command intent objectives coupled with the level of unintended negative consequences caused by inadequate vetting of targeting decisions against the rules-of-engagement and other operational constraints. Such a modeling strategy allows the modeler to construct a transparent "audit trail" that links national investments in information technology, leadership development, staff training, and personnel management and staffing policies to the quality of the actionable knowledge produced by a C2ISR system.

1.0 INTRODUCTION

In the introduction to his recent book on effects-based operations, Ed Smith cites the frustration of former Chief of Naval Operations, Admiral Mike Boorda, regarding the seemingly endless fielding of new military systems and platforms. [1] Much of this technology has been promoted on the basis of half-understood buzzwords or fashionable jargon. In response, Admiral Boorda is quoted as saying, "it sure would be nice if we had some clear idea what it was we were trying to do first."

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Such has been the case with the recent interest in effects-based operations. Just what is implied by this term, and what are its implications for the design of military command, control, intelligence, surveillance, and reconnaissance (C2ISR) systems? For decades, the defense research and development community has been locked into several Cold War paradigms that have constrained the design and application of C2ISR technology. These paradigms include (1) the basic notion of attrition warfare that places emphasis almost exclusively on the destruction of an adversary's military forces as a key to success and (2) the misguided interpretation of the *Observe-Orient-Decide-Act* (OODA) loop that defines C2ISR performance primarily in terms of information collection and management at the operational level of warfare. These paradigms have fostered a myriad of analytic models for studying the contribution or "value-added" of new collection systems, decision support systems, and so forth over the past several decades. Perhaps such models were useful back in the days when military power could be measured simply in terms of its ability to deter an invasion of Central Europe or, if necessary, defeat such an invasion by a superpower nation. However, as coalition operations in Kosovo, Afghanistan, and Iraq have recently demonstrated, the employment of military forces to achieve specific political objectives in an asymmetric environment of transnational terrorism has made the modeling of C2ISR performance significantly more complex.

Given the type of frustration once expressed by Admiral Boorda, it is important for the defense research and development community to build a clear understanding of what we are trying to accomplish with the fielding of future C2ISR systems and technologies. To this end, this paper revisits the basic purpose of a C2ISR system and examines how this purpose is fulfilled in the light of two transformational trends in military operations. The first trend, suggested above, is the evolution of warfare from the traditional Cold War model to a form that now emphasizes the political, military, economic, social, information, and infrastructure (PMESII) aspects of future operations and engagements. The second trend, brought about by the dawn of the Information Age, is the advent of network-centric warfare that enables multiple stakeholders and experts throughout a coalition to collaboratively plan and synchronize various aspects of an operation toward a common set of objectives. From this discussion, it is possible to identify the essential analytic elements to be represented in modeling C2ISR performance. As such, this presentation reflects some of the theoretic and analytic modeling work currently being undertaken by the US Air Force Research Laboratory to develop a future generation of C2ISR system simulation models. Such models are not based merely on the processes of collecting and managing the information workflow at the operational level of warfare, but rather explicitly depict the cognitive work process by which C2ISR systems generate actionable knowledge for the joint or coalition force commander. The aim of the discussion presented here is to describe a knowledge level modeling strategy that incorporates information management and workflow characteristics, and to illuminates the critical theoretic issues that must be addressed relative to future effects-based operations. Elements of the modeling will be described only to the extent necessary to achieve this objective. More details about the modeling constructs are planned to be reported at a later date.

2.0 EFFECTS-BASED PROBLEM SPACE

2.1 Characterizing Fourth-Generation Warfare

With the conclusion of major combat operations in both Afghanistan and Iraq, coalition forces face a much more complex challenge in the furtherance of its national security objectives –the emergence of what Colonel T.X. Hammes has termed fourth-generation warfare. [2] This form of warfare can be historically traced, beginning with the strategies of Mao Tse-Tung in China, and further developed conceptually by Ho Chi Minh in Vietnam, the FSLN and Sandinista movement in Nicaragua, and the Intifada movement in the Palestinian Occupied Territories. The concept of fourth-generation warfare differs significantly from the type of operation national military forces have been organized to conduct in recent years –rapid decisive defeat of a conventional military adversary, involving precision firepower and maneuver against a mechanized force that is controlled by a single, centralized command and control system. By contrast, fourth-generation warfare involves several unique elements that must be understood and disrupted if a coalition force is to prevail. At the strategic level, the goal of the conflict by the adversary is expressed primarily in political terms: the defeat of our political will to engage in a specific region of the world. The strategic tactic used is not conventional military defeat, but the convincing of the public and key coalition decision makers that the struggle is too costly on moral, human, economic, and social grounds. In terms of time scale, the adversary is prepared to wage this strategy over a period of years and bring it to successful completion only after achieving a convergence of political, economic, and social forces. At an operational and tactical level, a fourth-generation warfare adversary pursues operations primarily along the political, economic, and social dimensions of a region, conducting military operations typically in limited fashion and only where it furthers strategic interests. In fact, when engaged militarily, such an adversary will often resort to negotiating, pulling back, or even dissolving into the civilian populace since the strategic goal is not to win militarily, but to create the impression that the struggle is intractable.

To disrupt the operations of a fourth-generation adversary at the strategic, operational, and tactical levels, one must understand something about the unique nature of the adversary’s command and influence system. It reflects a “system of systems” organizational structure and process unlike the traditional command and control system employed by conventional military forces.

- First, the adversary will typically reflect a coalition of convergent interests rather than a single nation state or regime. Lacking a single “head” against which to develop a *coup d’oeil*, disrupting such a loose confederation will be based (1) identifying the critical linkages that bind these interests together and (2) developing strategies that can isolate or disrupt the cohesion of these interests.
- Second, the supporting elements of such an adversarial coalition exist at several tiers. At the top tier are found those insurgency leaders directly in charge of setting strategy and tactics. The second tier consists of those political, social, economic, religious, and even humanitarian organizations that lend indirect or covert support to the insurgency, but that otherwise fulfill a legitimate role within the region. The third tier consists of local population groups whose support and allegiance will change according to perceived needs of security and prosperity. Each of these tiers makes important contributions to the adversary’s overall strategy. Yet, each will require a different approach to disruption or manipulation.
- Third, there will exist multiple and overlapping networks of command and influence across each of the political, social, economic, religious, humanitarian, and military dimensions of the region. Since each of these dimensions contribute to a different facet of the adversary’s overall strategy, it will be important to understand the role, structure, and processes of each of these networks. Knowing where and how these networks intersect will also be an important step in their disruption.
- Fourth, given the diffuse and often informal nature of these various elements, a fourth-generation adversary accomplishes his strategic objectives through a combination of direct command and control, economic and social disruption, intimidation of specific individuals and groups, and the ability to exploit emergent crises for situational gain. Control of operations will be accomplished less through direct orders and more through establishing the local and global fitness conditions by which a complex, adaptive system evolves. Accordingly, disruption of these mechanisms will depend less on identifying and severing specific communication links and more on identifying and influencing the fitness conditions that shape behavior and outcome over the long run.

2.2 An Analytic Framework for Decomposing an Effects-Based Problem Space

Approaching this issue from a cognitive perspective, we see Hammes' definition of fourth-generation warfare as a prime example of a wicked problem space. The term *wicked problem* was originally defined by Horst Rittel and Melvin Webber. [3] Characteristics of wicked problem environments include (1) the problem is ill-structured so you don't understand it until you've developed a solution; (2) there is no "right" solution so problem-solving ends only when you run out of resources; (3) solutions are not right or wrong, simply "good enough" or "not good enough"; (4) each wicked problem involves a unique or novel set of factors and conditions; (5) every solution to a wicked problem is a "one shot solution" because you never get the opportunity to do it over; and (6) wicked problems have no obvious alternative solutions. In terms of the traditional OODA loop, wicked problem environments place greatest emphasis on the orientation stage of planning and decision making. Simply stated, a C2ISR system cannot properly engage in observing the battlespace and executing operational and tactical level decisions until it has adequately defined the nature of the problem at hand –or, to use a currently popular concept, it has *made sense* of the operational environment.

But what does sensemaking mean from a cognitive perspective? The answer to such a question has been debated extensively within several bodies of academic literature, including cognitive psychology, organizational psychology, and knowledge management.[1] However, for the purposes of this paper, sensemaking can be defined in terms of two broad activities: (1) clarifying and prioritizing the goals and constraints of a military operation and (2) characterizing and assessing the current state of the battlespace relative to these goals and constraints. Regarding the second activity, characterizing the battlespace implies (1) identifying the key dimensions and variables that can be used to predict cause and effect relationships, (2) discovering the key obstacles to achieving each desired goal, and (3) identifying potential action paths for overcoming each of those obstacles. In a very direct way, sensemaking is motivated by (and tied to) the need to plan and execute effective action, rather than simply a desire to acquire a general understanding of the world.

In terms of knowledge creation, sensemaking involves the appropriate assemblage of relevant information and relevant expertise into a dynamic (or working) mental model of the situation that can be used to plan, evaluate, and execute actions toward the achievement of a set of desired goals. Information consists of available cues and data provided by different C2ISR elements and other sources of intelligence. Expertise resides primarily within the experienced military and agency staff members who execute the various planning and decision making tasks within a C2ISR system's battle rhythm. Borrowing several concepts from Polanyi [5], expertise is represented in the form of *tacit knowledge* possessed by the staff members, whereas sensemaking involves using tacit knowledge along with available cues/data to build *focal knowledge* –a working mental model of the current situation. In a recent study, Winston Seick and a team of researchers from Klein Associates, Inc. define sensemaking in terms of a data/frame model. [6] According to Sieck *et al*, the purpose of the frame is to (1) define the elements of the situation, (2) describe the significance of these elements, (3) describe their relationship to each other, (4) filter out irrelevant messages while highlighting relevant messages, and (5) reflect the context of the situation, not just the data. Further, they note that, "…data elements are not perfect representations of the world, but are constructed. They are sampled from the available information in the environment and defined in terms of available frames." As seen in terms of the data/frame model, sensemaking is an iterative process in which the information gathering activities and mental construction activities are continually played off against one another in order to maintain the best interpretation of the current situation.

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[1] A current review of this literature can be found in a recent report by the first author. [4]

But what exactly might a frame look like for effects-based operations. To address this question, attention is turned to the work of Jens Rasmussen and his conceptualization of an *abstraction hierarchy*. [7] Here, Rasmussen and his research cohorts define a cognitive work space in terms of several dimensions, one of which is *means-ends relations*. These relations—expressed in terms of several levels of abstraction—are considered important when dealing with discretionary decision making –the type that typifies an effects-based military operation. The different levels of abstraction are based on Rasmussen's earlier development of his *abstraction hierarchy* for man-machine interface. These different levels of abstraction can be thought of as corresponding to an effects-based decomposition of a fourth-generation warfare operational environment.

The original concept of Jens Rasmussen envisioned a number of abstraction levels that moved from the more abstract purposed-based properties of a cognitive work space to the physics-based properties of the actual objects influenced by actions within the workspace. Taken together, these levels provide a framework for linking or associating one level of thinking to another. A typical abstraction hierarchy might include the following levels:

- *Purpose & Constraints* – The operational goals/objectives, constraints, and underlying values imposed on the operational work environment –*e.g.*, defeat a terrorist group as a military or political influence.
- *Abstract Functions* – The representation of scenario-independent concepts and principles that are useful to prioritize and coordinate across functions, to guide the overall flow of the operation, and to map system-specific functions onto the operational requirements –*e.g.*, coercive repression of a specific ethnic population or neighborhood by influencing their value mechanisms.
- *General Functions* – The representation of generalized functions performed by specific classes of objects that constitute the major system elements that must be coordinated or considered –*e.g.*, ethnic intimidation by means of random acts of terrorism or disruption of public services.
- *Work Processes and Equipment* – The representation of the actions and functions carried out by specific objects that are governed by both physical laws and human knowledge and conventions –*e.g.*, the placement of improvised explosive devices within a public area.
- *Physical Objects and Configurations* – The appearance, location, and configuration of physical objects that are considered relevant to the operational work environment –*e.g.*, a specific paramilitary cell or weapons cache.

2.3 Knowledge Elements of an Effects Tasking Order and Joint Targeting List

In the present modeling work, a simplified interpretation of Rasmussen's abstraction hierarchy has been adapted for representing the manner in which command intent at the strategic and operational level of decision making can be decomposed into knowledge elements that map directly to specific targeting decisions at the tactical level. Such decomposition is important in order to provide system analysts with an analytic framework or "audit trail" of how actionable knowledge is developed within a C2ISR system. That is, if the knowledge based characteristics of a primary information product of a C2ISR planning and decision making process can be explicitly represented at each stage of its development, then it becomes possible to analyze each operational development stage in terms that can connect knowledge generation to issues of information technology, staff training, leadership, personnel management, cultural differences, and various other factors that contribute (or inhibit) C2ISR system performance.

The general framework employed in our modeling work is illustrated in Figure 1. At the left of the diagram, we begin by listing the various coalition objectives that might be given to the military commander. Next, each of these objectives is associated with a desired endstate or set of endstates. Corresponding to each endstate is an abstract entity defined as a *center of gravity* (CoG). The concept of a center of gravity is taken from a number of theoretical developments in the US Air Force. In this literature, a CoG has been variously defined as (1) a source of strength within an adversary's force structure, (2) a point of weakness that can be exploited, or (3) simply a point of leverage that can be influenced to achieve some desired endstate or effect. At its most basic definition, a CoG represents a political, military, economic, social, information, or infrastructure entity that can be potentially influenced to achieve a desired coalition endstate. Thus, each CoG can be associated with a specific type of effect or set of effects that the commander deems appropriate. In the present research, a CoG represents an abstract entity around which a commander can focus the operational level of attention of a C2ISR system in an effects-based operation.

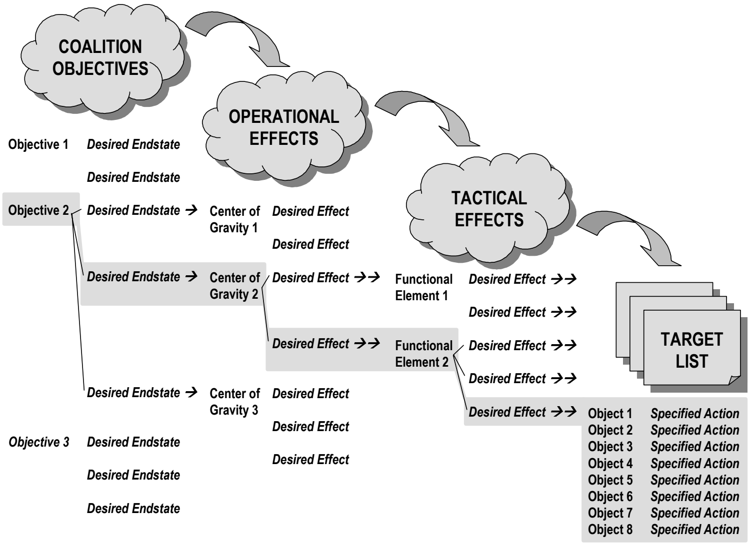

Figure 1: Abstract Decomposition of an Effects-Based Operation.

In a similar fashion, each of the CoG effects can be associated with a corresponding functional element that reflects the operational focus of that effect. In turn, each of these functional elements can be decomposed into a desired tactical effect (or set of effects) that is thought by the commander and his staff to contribute to achieving the operational effect. Moving to the next level, each of the tactical effects associated with functional elements can be associated with a set of battlespace objects or nodes. Whereas objectives, CoGs, and functional elements were each defined in abstract terms, objects or nodes represent physical entities within the battlespace that can be detected by the C2ISR system and acted upon by the coalition force.

Although the abstraction hierarchy framework is somewhat of a modeling artifact, its structure corresponds roughly to what might be the knowledge products at different stages in a future coalition headquarters' planning process. For example, the identification of coalition objectives would correspond to the general content of a commander's mission statement. In a similar fashion, the identification of key centers of gravity, supporting functional elements, and the associated effects desired against these entities might correspond to a prioritized effects list that is published by a joint/coalition headquarters for a given phase of operation. Finally, the list of nodes or objects associated with each functional element provides the cognitive basis for developing a prioritized target list that can be executed by each of the component (air, land, naval, special operations) commands and coordinating agencies (*e.g.*, diplomacy, legal, humanitarian, economic development).

In terms of assessing performance, the abstraction hierarchy framework provides the basis for developing an analytic "audit trail" for the modeler. For example, as each component command executes a daily set of missions against the prioritized target list, successful missions can be accounted for in terms of which functional elements they neutralize. Moving upward in the framework, the neutralization of functional elements can be accounted for in terms of which centers of gravity they support. Finally, as the centers of gravity are engaged, one can assess the degree to which each coalition objective is being achieved. Obviously, such rigid accounting is not practical in the real world, but such a scheme provides the modeler with an approximate method of assessing the quality and relevance of the C2ISR planning process.

2.4 Fourth-Generation Warfare Illustrations

To illustrate how the concept of an abstraction hierarchy might be applied, let us consider the following hypothetical scenario. Such a scenario might be driven by the desire of a coalition force to neutralize an international terrorist organization's base of training and operation within a specific region, along with the deposition of a hosting nation's corrupt political leadership. At the same time, the intention of the coalition force is to accomplish these goals by (1) separating the terrorist organization and corrupt political leaders from the nation's traditional military forces, (2) providing the basis for subsequent stabilization and economic reconstruction of the region's ethnic populations, and (3) respecting the legitimate cultural and political factions within the region. Temporally, such a scenario might be divided into specific operational phases—*e.g.*, setting conditions, initial forced entry, decisive action, stability and reconstruction—with each phase having a specific set of objectives, constraints, and priorities. Such a hypothetical scenario implies the need for a very complex set of effects-based actions and outcomes. To see how these actions and outcomes might be cognitively framed, we consider three illustrative examples taken from the hypothetical scenario developed for this research.

The first example is taken from what might be considered the first operational phase of a military campaign, setting the conditions for success. One possible objective within this phase might be "*Shape the battlespace to achieve the desired outcome with minimal time and cost.*" As illustrated in Figure 2, such an objective can be decomposed into several desired endstates. In turn, each of these endstates can be associated with a specific center of gravity, an abstract entity that reflects the focus of the endstate. For example, the political endstate, "*Internal insurgent forces have been aligned to support the operational campaign*," can be associated with the CoG labeled "*Internal insurgency forces and their associated tribes/clans*." In a similar fashion, this CoG can decomposed into two specific operational level effects, "*Internal insurgency groups have been provided with the means (e.g., C2 and weapons) to effectively support campaign objectives*" and "*Liaison personnel have been established with each insurgency force to coordinate operations with coalition forces*." Moving to the right, the first area of operational effect can be associated with the functional entity labeled "*Individual insurgency cells located throughout the battlespace*." The tactical level effect to be achieved against this functional element is then defined as "*Covertly supply with weapons and supplies (D-20 thru D-1)*." Notice at this level that the effect begins to articulate a sense of timing that corresponds with the first operational phase of the campaign. Finally, this desired effect at the tactical level can be associated with a set of specific objects or nodes within the battlespace. These objects or nodes provide the basis for developing both intelligence collection plans and operational orders within the component commands.

The second example (Figure 3) is taken from the decisive action phase of the military campaign. This example reflects more of a traditional type of military targeting problem. Here, one objective would be "*Identify and eliminate the adversary's weapons of mass destruction (WMD) capability*" with a desired endstate of "*WMD stockpiles, delivery systems, and supporting infrastructure are destroyed or placed under positive control of coalition inspection teams*." Associated with this desired endstate are several centers of gravity, one of which is labeled "*Adversary's weapons of mass destruction laboratories and production facilities*" with a desired operational level effect of "*WMD laboratories and production facilities are identified and placed under positive control of coalition inspection teams*." Associated with this operational level effect is the functional element labeled "*WMD research laboratories and production facilities*" with a desired tactical level effect of "*Captured and placed under positive control as evidence for criminal proceedings (D+6 thru D+35)*." Finally, this desired effect at the tactical level can be associated with a set of specific objects or nodes within the battlespace. These objects or nodes provide the basis for developing a coordinated set of actions within the component commands to secure specific WMD laboratory and production sites during this phase of the operation.

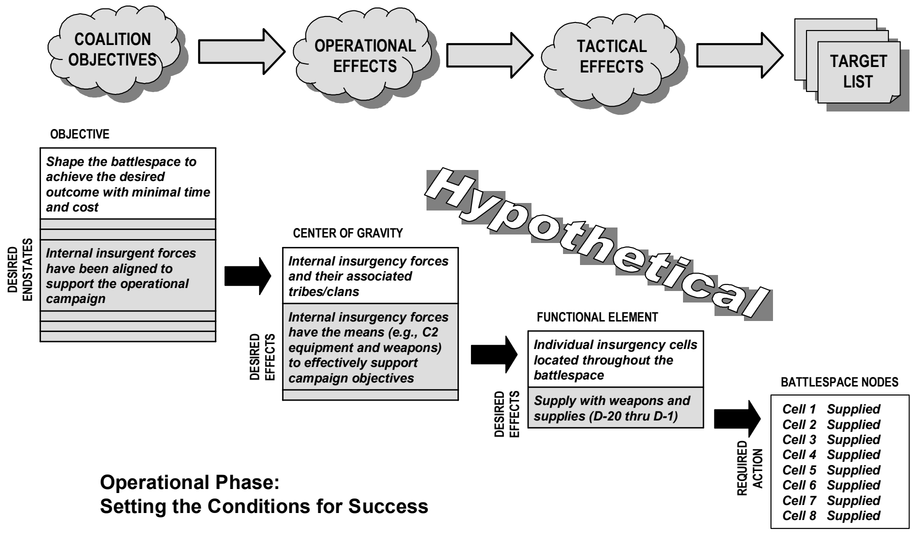

Figure 2: Example Decomposition: Setting Conditions for Success.

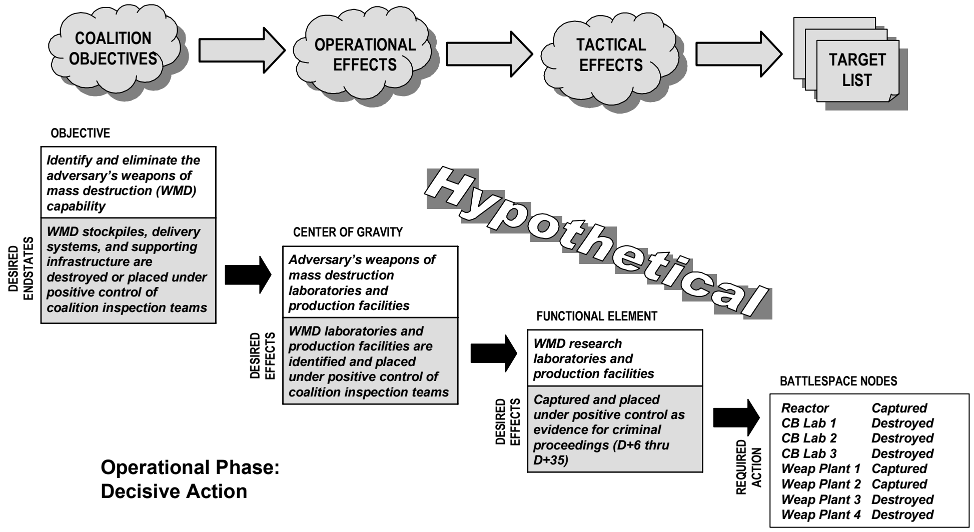

Figure 3: Example Decomposition: Decisive Action.

The final example (Figure 4) is taken from a possible stability and reconstruction phase of a military campaign. A possible objective during this phase might be "*Establish interim conditions for 'next state' in the stability process*" with one (of several) desired endstate being "*Civil administration and civil police functions are effectively restored and able to assume responsibility for internal public order*." Corresponding to this desired endstate would be several centers of gravity, one of which is labeled "*Local city, town, and village civil administration*" with a desired operational level effect of "*Local civil administration functions are restored to effective functioning*." This operational level effect can then be decomposed into its supporting functional elements, one of which is "*TV/radio/newspaper media*" with a desired tactical level effect of "*Positive reporting to promote sense of optimism and normalcy, weekly (D+150 thru D+300)*." Finally, this desired effect at the tactical level can be associated with a set of specific objects or nodes within the battlespace. These objects or nodes provide the basis for developing a set of information operation actions within the component commands.

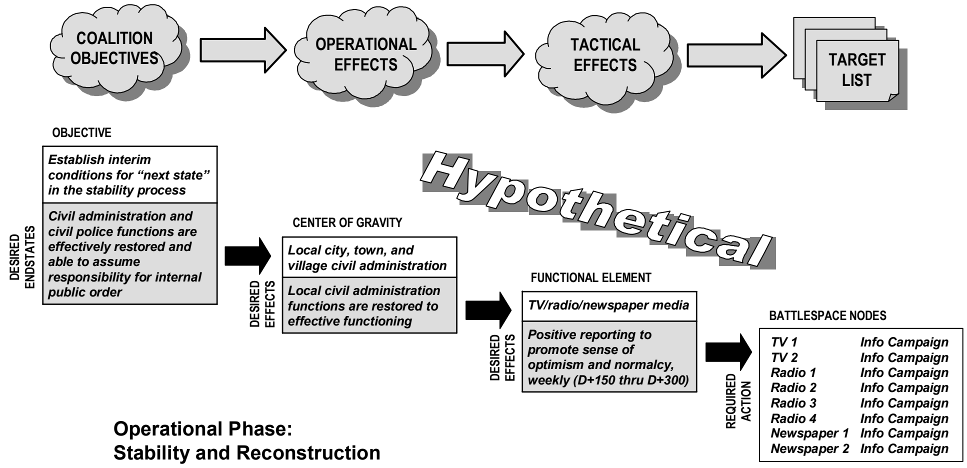

Figure 4: Example Decomposition: Stability and Reconstruction.

3.0 LINKING KNOWLEDGE WITH ORGANIZATIONAL PROCESS

The framework described in the preceding section reflects an "ideal" state of actionable knowledge as it might be developed within a coalition C2ISR planning system. However, in the real world, the knowledge product that emerges from the planning process would be of variable quality, depending upon (1) the expertise and information available either within the headquarters staff or from reach-back and (2) the effectiveness of the collaboration process that brings together this information and expertise from various stakeholder elements and agencies. It is the representation of these issues—and all of the variables that impact on them—that is important in the modeling of C2ISR systems and processes. Such a challenge is precisely what motivated the current work of the authors of this paper. While the details of these modeling aspects are beyond the scope of this paper, this next section briefly outlines a number of points relevant to these issues.

3.1 Representing the Role of Expertise in the Knowledge Creation Process

As noted by John Seely Brown and Paul Duguid, the creation of actionable knowledge within any organization requires the successful integration of two elements –the "*know-what*" and the "*know-how*." [8] The know-what within a military C2ISR organization is currently reflected in what some call the Common

Operating Picture (COP). The COP—often being supported by information management and intelligence fusion technology—largely views the operational environment from a positivist-based analytic perspective. That is, the COP is predicated upon the assumption that the battlespace can be empirically observed and that these observations can be objectively fused using a purely deductive logical formalism into an overall awareness of the battlespace. It is further assumed that the facts and descriptions comprising this awareness can be universally shared –*i.e.*, that its meaning is universally defined independently from the perspective of the individual. By contrast, the know-how within a military C2ISR organization is largely reflected in the tacit knowledge of the commanders and their supporting staff. Tacit knowledge—reflecting the past training, experience and expertise of each individual—largely views the operational environment from a constructivist perspective. That is, tacit knowledge is used by the individual to dynamically construct situational meaning by processing a continuous stream of input cues against a store of experience-based cases and mental model fragments –as discussed earlier with the citation of Sieck *et al*.

Modeling information flow from a set of battlespace sensors and intelligence collection systems is rather straightforward, as has been demonstrated by numerous C2ISR simulations developed over the past several decades. Modeling the nature and use of tacit information is a bit trickier –particularly since tacit knowledge is, by definition, inexpressible in explicit form. Thus, the challenge of developing a veridical mode of C2ISR operations involves the realistic representation of how the tacit knowledge possessed by the commanders and their staffs serves to interpret, filter, shape, and frame the use of the know-what provided through the COP and other networked information channels. In the current research project, this representation is enabled through the use of the Leontief input-output matrix that serves as an approximation of how an individual transforms a set of environmental cues into a working knowledge product—how objective data with universal meaning is converted by an expert into constructed knowledge used to guide action taking.

The basic process is illustrated in Figure 5. At the left of this figure is an input-output matrix reflecting "ideal knowledge" that the modeler defines as the baseline or reference goal of the C2ISR system for a given planning task. The task input stimuli are represented in the form of information cues that are passed to a specific step in the planning process. For example, the input cues might represent key centers of gravity and selected characteristics identified in a preceding step of the planning process. The "X" values represent the "correct" functional elements that should be associated with the various centers of gravity. Application of the matrix to the vector of input stimuli results in the "correct" identification of specific functional elements that should be engaged in order to influence the identified set of CoGs.

By contrast, the matrix at the right of this figure reflects the knowledge of a specific staff actor[2] portrayed in the C2ISR process model. Here, the ideal knowledge "X" values have been replaced by probability values that reflect the likelihood that this specific actor will recognize a meaningful relationship between specific input cues and knowledge output associations. In this manner, we have accounted for the actor's tacit knowledge in stochastic form. As suggested by this paradigm, the more closely an actor's task knowledge matrix matches the ideal, the more expertise the actor can be said to possess. Low probability values within this type of matrix suggest a low (naïve) level of expertise, with missing values indicating areas of the operation that lie outside of the actor's domain of expertise. Using this general modeling scheme, it is possible to approximate the type of tacit knowledge employed at each stage of the planning process. That is, separate actor task knowledge matrices can be used to model the staff's ability to decompose operational objectives into key CoGs, CoGs into relevant functional elements, functional elements into specific battlespace nodes, and so forth. In a similar fashion, specific actor task knowledge matrices can be used to reflect knowledge of critical operational

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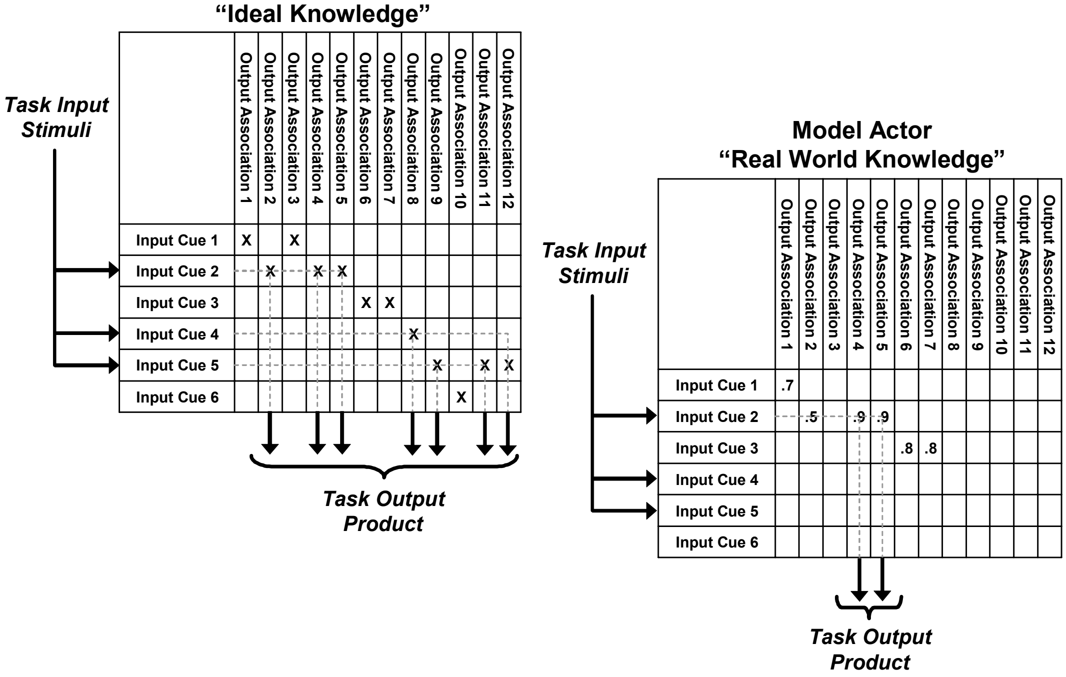
[2] Actors are nominally considered to be human experts serving in a specific staff role; however, this methodological approach can be extended to portray decision support tools, knowledge bases, and other machine aids as specific actors within a planning process.

constraints –*e.g.*, rules-of-engagement and other imposed restrictions that serve to prevent the production of unintended negative political, social, legal, military, economic, or humanitarian consequences caused by planned military actions.



"Ideal Knowledge"

	Output Association 1	Output Association 2	Output Association 3	Output Association 4	Output Association 5	Output Association 6	Output Association 7	Output Association 8	Output Association 9	Output Association 10	Output Association 11	Output Association 12
Input Cue 1	X		X									
Input Cue 2		X		X	X							
Input Cue 3						X	X					
Input Cue 4								X				
Input Cue 5									X		X	X
Input Cue 6										X		

Model Actor "Real World Knowledge"

	Output Association 1	Output Association 2	Output Association 3	Output Association 4	Output Association 5	Output Association 6	Output Association 7	Output Association 8	Output Association 9	Output Association 10	Output Association 11	Output Association 12
Input Cue 1	.7											
Input Cue 2		.5		.9	.9							
Input Cue 3						.8	.8					
Input Cue 4												
Input Cue 5												
Input Cue 6												

Figure 5: Tacit Knowledge Matrix.

3.2 Organizational Knowledge Creation

The utility of representing actor task knowledge in the form of a Leontief input-output matrix is further seen when considering the process of collaborative knowledge creation within an effects-based targeting process. As indicated earlier, fourth-generation warfare demands that military operations be coordinated with political, economic, social, information, and infrastructure actions in order to accomplish the overall goals of a coalition force. This implies the need for the C2ISR system to be able to bring together many different areas of expertise from across various networked organizational elements and external agencies. The quality of the effects-based operational plan that emerges from the C2ISR organizational process will, in large part, depend upon whether or not the right areas of expertise are brought together in collaborative form for each task step in the planning process.

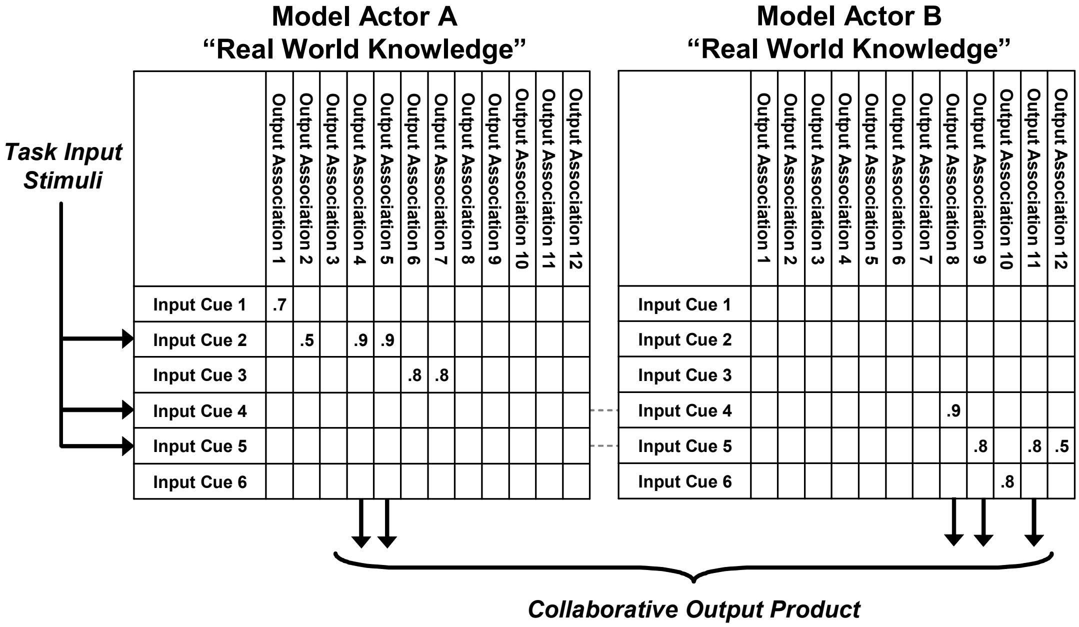
To better understand how organizations create actionable knowledge within a collaborative environment, the current research draws upon two bodies of research. The first area of research, illustrated by the writings of Ikujiro Nonaka and Hirotaka Takeuchi, reflects an eastern epistemological tradition –one that views teams and organizations in organic ways and emphasizes the subtle processes by which teams and organizations create knowledge. [9] By contrast, the second area of research, illustrated by the writings of Thomas Davenport and Laurence Prusak, reflects a western epistemological tradition –one that views teams and organizations in mechanistic ways and sees them as a mechanism for sharing information and knowledge. [10] Taken together, these two views add to our understanding of what is important to capture or reflect in future models of command and control.

Using the paradigm of organizations as amplifiers of individual knowledge, Nonaka and Takeuchi emphasize the process by which teams and organizations continuously create new knowledge –a process referred to as "*chishiki keiei*". Structurally, Nonaka and Takeuchi define organizations in terms of three elements: *knowledge base*, *business system*, and *project team*. The *knowledge base* of an organization consists of both tacit and explicit knowledge. Tacit knowledge is represented in the form of the expertise, culture, and heuristic procedures possessed by the organization. Explicit knowledge is represented in the form of documents, filing systems, and databases. Within a C2ISR organizational context, explicit knowledge includes the COP as well as plans, briefings, and other information available from the organization's intranet. This element serves as a knowledge archive or corporate university for the organization. The *business system* represents the rules, hierarchies, and structured activities by which the organization carries on its normal, routine operations. The analogy of this in a military setting would be the formal reporting channels, daily battle rhythm of scheduled meetings and briefings, formal approval authorities, and the planning and briefing document templates employed within a headquarters. The final element consists of *project teams* –multiple, loosely interlinked, situationally-driven, and self-organizing patterns of collaboration within the organization that form in response to emergent issues and specific operational planning problems. Here, project teams are reflected in the various planning and coordination boards, working groups, and centers that are formed from across the staffs within each military headquarters.

As defined by Nonaka and Takeuchi, all three elements are essential for effective knowledge creation within an organization. The knowledge base—consisting of both tacit and explicit expertise—provides the basic building blocks of individual knowledge and shared situation awareness. The business system in the middle provides the predictable and cyclical framework for focusing the sensemaking activities of the project teams toward useful and purposeful goals, and for synchronizing their knowledge products into cohesive decisions and actions. Finally, the ad hoc project teams provide the emergent and adaptive collaboration mechanism by which individual areas of knowledge or expertise are combined and synthesized to create actionable knowledge and shape the organization's decision space. In terms of modeling collaborative knowledge creation, it is important to reflect all three elements within a C2ISR organization; however, specific attention must be given to the representation of project teams –i.e., the planning and coordination boards, working groups, and centers that actually carry out the process of collaborative knowledge creation. This is the most opportunistically and fluidly structured part of the organization and hence, it is the most difficult to model consistently in terms of knowledge.

The general process of collaborative knowledge creation envisioned within the current research is illustrated in Figure 6. Depicted in this figure are the tacit knowledge matrices of two different actors collaboratively engaged in a specific planning task. Comparing the probability values reflected in these two matrices, we observe that each actor possesses a different area of expertise. For a given set of task input cues, each actor is able to develop only a limited set of task output associations. Taken together, however, we see that their combined effort produces a more comprehensive knowledge product for this particular task. Employing this general paradigm across each of the collaborative tasks within a C2ISR planning process, the model is able to capture the effect of bringing together multiple areas of expertise to develop different parts of an effects-based operations plan. As a side note, such a model can also approximate the effect of learning and mentoring –i.e., the collaborative work process can be used to modify each actor's tacit knowledge matrix by changing certain probability values in accordance with the matrices of other actors engaged in the same task.

In a second body of work, Thomas Davenport and Laurence Prusak depicts a team or organization operating as a marketplace of information and knowledge. Operating within this marketplace are four types of knowledge actors: managers, sellers, buyers, and brokers. *Managers* decide on the goals to be pursued by the organization, identify the issues to be addressed and resolved in order to attain those goals, and evaluate the relevance and utility of knowledge generated within the marketplace. *Knowledge sellers* represent the functional experts within (or available to) a team or organization. They each possess some type and degree of tacit experience or expertise that is deemed valuable for interpreting and understanding specific aspects of the operational situation. Unless this tacit knowledge is identified and appropriately utilized within the planning and decision making process, its value remains only potential and not actualized. *Knowledge buyers* are defined by Davenport and Prusak as those individuals responsible for problem-solving. However, the term "problem-solving" is interpreted here in a broad sense to imply (1) the existence of wicked or undefined operational problems, (2) the synthesis and reconciliation of multiple perspectives in order to appropriately construct a problem space, and (3) the need for teams and organizations to develop a common ground of understanding upon which to develop cohesive plans and synchronized action. As they engage in problem-solving, knowledge buyers are the key to linking tacit experience and expertise to action. *Knowledge brokers* are those actors within a team or organization that either (1) control access to specific experts and information) or (2) act as boundary spanners between different communities of practices in order to facilitate the integration of different areas of expertise.



Model Actor A	Output Association 1	Output Association 2	Output Association 3	Output Association 4	Output Association 5	Output Association 6	Output Association 7	Output Association 8	Output Association 9	Output Association 10	Output Association 11	Output Association 12
Input Cue 1	.7											
Input Cue 2		.5		.9	.9							
Input Cue 3						.8	.8					
Input Cue 4												
Input Cue 5												
Input Cue 6												

Model Actor B	Output Association 1	Output Association 2	Output Association 3	Output Association 4	Output Association 5	Output Association 6	Output Association 7	Output Association 8	Output Association 9	Output Association 10	Output Association 11	Output Association 12
Input Cue 1												
Input Cue 2												
Input Cue 3												
Input Cue 4								.9				
Input Cue 5									.8		.8	.5
Input Cue 6										.8		

Figure 6: Collaborative Use of Tacit Knowledge Matrices from Multiple Actors.

For the team or organization to make appropriate and timely decisions, the marketplace must support the appropriate and timely sharing and distribution of knowledge. Davenport and Prusak argue that this is most effectively carried out through personal conversations and face-to-face meetings –a practice that is increasingly being influenced by electronic networking and virtual meetings. However, they identify several obstacles or "frictions" within a team or organization that can inhibit the transfer of knowledge:

- *Lack of trust* (immature social networks or inadequate face-to-face contact);
- *Different cultures, vocabularies, and frames of reference* (lack of common ground);
- *Lack of time and meeting places* (inadequate opportunity for collaboration);

- *Status and rewards go only to knowledge owners* (lack of inter-organizational incentive for sharing);
- *Lack of absorptive capacity in recipients* (inadequate staff training and leadership development);
- *Belief that knowledge is prerogative of specific groups* (parochialism, not-invented-here); and
- *Intolerance for mistakes or need for help* (organizational inflexibility in the face of novel situations).

Although not addressed by Davenport and Prusak, the advent of networked teams and organizations present an additional set of obstacles or "frictions" that must be considered for virtual collaboration. These would include

- *Inadequate expressive power provided by collaboration tools* (constrained message formats or lack of expressive tools) and
- *Inadequate or unreliable connectivity* (inadequate bandwidth or access to intranet).

In terms of modeling collaborative knowledge creation within a C2ISR organization, it is essential that each of these various classes of obstacles be represented. In this manner, it becomes possible to analytically examine the impact of a wide variety of influences on C2ISR system performance. Such influences include both (1) technology such as collaboration and decision aiding tools and (2) socio-cognitive initiatives such as leadership development, staff training, and personnel management and staffing policies. While the details of how such variables can be modeled are beyond the scope of this paper, the general strategy employed in the current research is to account for these various influences in the design of the various collaborative planning tasks that bring together the various areas of expertise required by the effects-based planning process.

4.0 KNOWLEDGE METRICS

As a final part of this discussion, attention is briefly turned to the issue of knowledge metrics. The construction of analytic models of C2ISR systems and organizations should always be undertaken with goal of measuring and assessing key areas of performance. But what are the appropriate metrics of performance for an effects-based targeting model. Here, the current research focuses on the two critical aspects of targeting performance: (1) the contribution of targeting operations to overall command intent and (2) the inadvertent development of unintended negative political, social, legal, military, economic, or humanitarian consequences caused by planned military actions. In this regard, the presented frameworks for (1) decomposing command intent into specific targeting actions, (2) representing individual tacit knowledge, and (3) modeling the collaborative use of different areas of expertise combine to facilitate an explicit examination of these two aspects of targeting performance.

The two general dimensions of coalition targeting performance are illustrated in Figure 7. As depicted in the figure, a variety of different technological, cognitive, social, and organizational variables impact on C2ISR system performance. These variables can drive C2ISR system performance along two dimensions: (1) the efficient or inefficient use of diplomatic, information, military, and economic actions for achieving command intent and (2) the proper or inadequate vetting of these actions regarding rules of engagement and other operational restrictions. Each of these dimensions is a direct reflection of the quality of the actionable knowledge produced within the C2ISR organization. By modeling the creation of this knowledge in the manner outlined in this paper, it is possible for the analyst to develop a transparent "audit trail" between national investments in collaboration and decision aiding tools, leadership development, staff training, and personnel management and staffing policies.

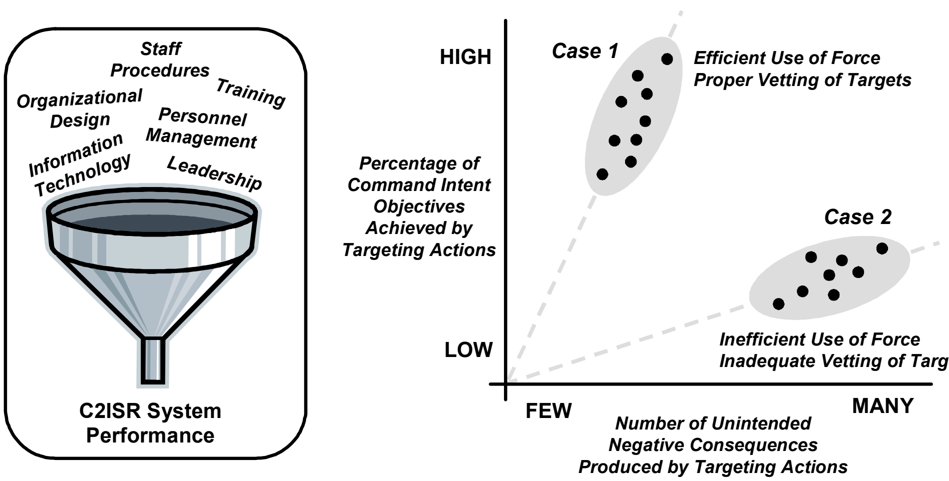


Figure 7: C2ISR System Performance Dimensions.

5.0 SUMMARY

This paper has presented an overview of the modeling issues relevant to portraying the construction of actionable knowledge within an effects-based targeting process. At the heart of these issues is the need to consider the various political, military, economic, social, information, and infrastructure dimensions that characterize a future coalition operation against a fourth-generation adversary. Unlike the classic attrition warfare models of the Cold War era, this type of warfare reflects a wicked problem space in which a major challenge for any C2ISR system will be the proper framing of actions within this multi-dimensional battlespace. Current modeling research undertaken by the authors has demonstrated one possible approach to this challenge –the abstract decomposition of command intent objectives into key centers of gravity, functional elements that support these centers of gravity, and the battlespace nodes that comprise each functional element. This type of abstraction hierarchy approximates the cognitive framework currently proposed by some military analysts for developing meaningful target lists within an effects-based operation.

A second critical modeling issue is the need to explicitly represent the types of tacit knowledge that must be combined with situation awareness to constructively develop this cognitive framework. Again, the current research undertaken by the authors demonstrates how a data/frame model of sensemaking can be analytically represented by the use of a Leontief input-output matrix. Such a matrix allows the modeler to approximate each actor's tacit knowledge in the form of association probabilities that relate a set of task input cues to a second set of task output knowledge products. By adjusting these probability values, the modeler can specify the areas and depth of knowledge that an actor brings to a specific planning task.

A third critical issue is the need to explicitly portray how a C2ISR organization uses its staff structure and battle rhythm to bring together appropriate areas of expertise for each step in an effects-based targeting process. Here, effective collaboration is seen to bring together multiple sets of tacit knowledge to build a more comprehensive knowledge product at each step in the planning process. This is handled analytically by portraying how the tacit knowledge matrices of different actors can be used in combination. In addition, a variety of collaboration obstacles—technological, cognitive, social, and organizational—can also be represented within the model as influencing the process by which the C2ISR identifies, links, and facilitates specific sets of actors to represent different stakeholders and areas of expertise. Such a modeling strategy allows the modeler to construct a transparent "audit trail" that links national investments in information technology, leadership development, staff training, and personnel management and staffing policies to the quality of the actionable knowledge produced by a C2ISR system.

A final issue is the need to identify a clear set of metrics for assessing the performance of a C2ISR system within this type of multi-dimensional battlespace. Here, two basic measures of performance are identified: (1) the degree to which the planned targeting actions achieves overall command intent objectives and (2) the level of unintended negative consequences caused by inadequate vetting of targeting decisions against the rules-of-engagement and other operational constraints. Such metrics reflect that fact that the basic product of a C2ISR system is not simply information, but is actionable knowledge that guides the efficient and effective execution of various diplomatic, information, military, and economic actions within a battlespace.

A full and detailed articulation of the modeling approach currently being undertaken by the authors is beyond the scope of this paper. However, the preceding discussion has outlined what are many of the novel aspects of this work –specifically with regard to the explicit representation of knowledge creation within a coalition C2ISR system.

REFERENCES

[1] Smith, Edward. A. (2002). Effects-Based Operations: *Applying Network Centric Warfare in Peace, Crisis, and War*. Washington, DC: DoD Command and Control Research Program.

[2] Hammes, T.X. (2004). 4th-generation warfare. *Armed Forces Journal*, November 2004.

[3] Rittel, H. & Webber. M. (1984). Planning problems are wicked problems, in N. Cross (Ed.) *Developments in Design Methodology*. New York: John Wiley & Sons. pp. 135-144.

[4] Leedom, D.K. (2004). *The Analytic Representation of Sensemaking and Knowledge Management within a Military C2 Organization*, AFRL-HE-WP-TR-2004-0083. Wright-Patterson AFB, OH: US Air Force Research Laboratory.

[5] Polanyi, M. (1962). *Personal Knowledge: Towards a Post-Critical Philosophy*. Chicago, IL: University of Chicago Press.

[6] Sieck, W.R.; Klein, G.; Peluso, D.A.; Smith, J.L. & Harris-Thompson, D. (2004). *FOCUS: A Model of Sensemaking* (Final Technical Report, Contract 1435-01-01-CT-31161, US Army Research Institute). Fairborn, OH: Klein Associates, Inc.

[7] Rasmussen, J.; Petjersen, A.M. & Schmidt, K. (1990). *Taxonomy for Cognitive Work Analysis*. Roskilde, Denmark: Riso National Laboratory.

[8] Brown, J.S. & Duguid, P. (1998). *Organizing knowledge*. California Management Review. Spring 1998, Vol. 40, No. 3; pp. 90-111.

[9] Nonaka, I. & Takeuchi, H. (1995). *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*. New York: Oxford University Press.

[10] Davenport, T. & Prusak, L. (1998). *Working Knowledge: How Organizations Manage What They Know*. Boston, MA: Harvard Business School Press.