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THE SIMULATION OF SENSEMAKING AND KNOWLEDGE MANAGEMENT WITHIN A JOINT EFFECTS-BASED PLANNING SYSTEM

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ABSTRACT

This paper describes key aspects of research funded by the US Air Force Research Laboratory to develop a working simulation model of an effects-based targeting process as it might be reflected in a future coalition task force headquarters and subordinate component command headquarters. The modeling research is based on prior theoretical work that characterized the essential sensemaking and knowledge management work flows within an operational headquarters. The present modeling project uniquely integrates two areas of modeling. The first area of modeling focuses on the explicit representation of the knowledge framework (abstraction hierarchy) required for decomposing command intent into actionable knowledge within each of the political, military, economic, social, information and infrastructure (PMESII) dimensions of the battlespace. The second area of work focuses on the explicit representation of the staff work flow and patterns of collaboration within the various centers, working groups, cells, and teams that build this knowledge framework. Together, these representations allow the analyst to assess the influence of information technology, training, leadership, personnel management, cultural differences, and organizational design on the quality of the knowledge product (e.g., Effects Tasking Order, daily Air Operations Order) emerging from the command and control process.

INTRODUCTION

This paper focuses on the modeling of human sensemaking and decision making within a future joint or coalition military command, control, intelligence, surveillance, and reconnaissance (C2ISR) system. In particular, it describes key aspects of the approach being taken by the authors to couple the modeling of cognitive workflow within a networked structure of military headquarters with the explicit modeling of the knowledge products being constructed by that workflow. The goal of this research is to provide the Air Force, as well as the broader defense research community, with the foundation for a new generation of C2ISR simulation models that is capable of assessing the specific influence of information technology, training, leadership, personnel management, cultural differences, and organizational design on system performance.

A Paradigm Shift

The advancement of scientific research in a particular area of study—for example, the modeling of human decision making within a military C2ISR system—typically derives from the common acceptance of a specific, organizing *paradigm*. Here, Thomas Kuhn defines a paradigm as being a collection of beliefs shared by scientists, a set of agreements about how theories and problems should be understood.[1] A common paradigm adopted for the modeling of C2ISR systems has been John Boyd's "*Observe—Orient—Decide—Act*" (OODA) loop. In his original conception of the OODA loop (Figure 1), Boyd placed considerable emphasis on the *Orient* stage of command and control operations, showing it to be a complex interaction of genetic heritage, cultural tradition, previous experience, new information, and analysis and synthesis.[2] Decision making was seen to involve both hypothesis formulation followed by action that served to test each hypothesis. At the same time, the original model contained multiple, cross-referencing feedback paths that served to reshape the *Observation* stage in terms of guidance provided by the other three stages.

As useful as this paradigm has been for helping analysts to think about military C2ISR, the OODA loop paradigm has unfortunately led some researchers to distort or oversimplify the decision making process in the C2ISR context. To date, most attempts to reflect the OODA loop paradigm in modeling and simulation have ignored the complexity of the *Orient* stage, and have assumed the process to be only forward directed without any backward feedback loops. In extreme cases, the OODA loop paradigm has been reduced to simply an observation stage followed by minimal or rote information processing, which then leads to simple, rule-based tactical actions. Understandably, such distortions have led some researchers and analysts to conclude that (1) simply collecting more information (observations) will lead to better military decision making; (2) decision making performance is based solely on the amount of information collected (often stated in terms of the degree to which "ground truth" is accurately portrayed in the observations); and (3) the process of formulating data into information, information into knowledge, and knowledge into action is a one-way, bottom-up cognitive or computational process.

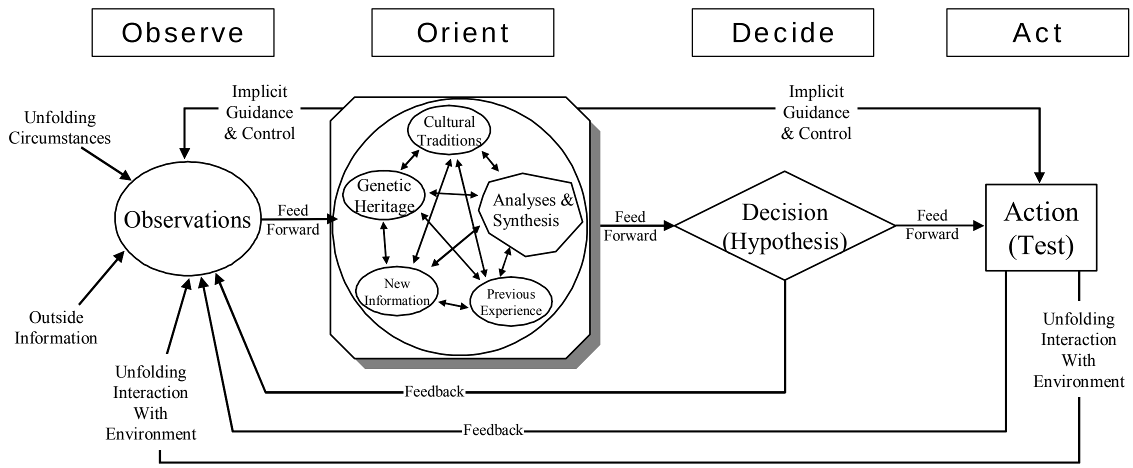

Figure 1 John Boyd's Original Conception of the OODA Loop

Within the past several years, however, interest has arisen within the defense research community regarding the topics of sensemaking and knowledge management, as these processes are manifested within military C2ISR organizations.[3] Current literature within these areas of research has correspondingly led to a refocusing on the *Orient* stage of Boyd's OODA loop paradigm. In this regard, the authors undertook a review of this literature to identify a new set of paradigms with which to characterize and model this critical stage of military command and control operations. Motivating this research have been two aspects of defense transformation in recent years: (1) the advent of new and more complex forms of warfare over recent years that involve a spectrum of political, military, economic, social, information, and infrastructure (PMESII) dimensions and (2) the dawn of the Information Age that brings the potential for knowledge management across a networked set of military headquarters and coordinating agencies.

Fourth-Generation Warfare: the Increasingly Complexity of Operational Planning

With the conclusion of major combat operations in both Afghanistan and Iraq, military 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*.[4] 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 more diffuse "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 on (1) identifying the critical linkages that bind these interests together and on (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.

The characteristics of fourth-generation warfare place new demands upon military C2ISR systems and organizations. Specifically, it is increasingly recognized that the planning and execution of military operations will take place with a battlespace characterized by important political, military, economic, social, information, and infrastructure dimensions. Within such a context, military operations must be synchronized with a host of other diplomatic, information, and economic actions that are each designed to influence a future adversary and battlespace in specific, intentional ways. Planning and coordinating such multi-dimensional operations will be a daunting task for any set of military headquarters. In turn, command intent must be articulated and translated into specific effects-based actions within a cognitive framework that acknowledges these various battlespace dimensions and classes of action.

Wick Problem Environments: the Need for Collaborative Sensemaking and Knowledge Management

Corresponding to the emergence of information technology in the latter half of the 20th century, interest began to grow in the question of how organizations—*e.g.*, large corporations, research institutes, military headquarters—create useful knowledge. Underlying this interest was the naïve belief that technology could provide information superiority which, in turn, would automatically translate into knowledge superiority and competitive advantage. However, results within both private industry and government have brought the realization that, in real world, the issue is a bit more complicated. In large part, this realization came about when it was discovered by some technology experts and management scientists that there is often no direct correlation between information technology investments and organizational performance.[5]

Underlying this issue is the "*wick*" nature of the problem environment in which a decision making organization often operates. As originally defined by Horst Rittel and Melvin Webber, characteristics of wick 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 wick problem involves a unique or novel set of factors and conditions; (5) every solution to a wick problem is a "one shot solution" because you never get the opportunity to do it over; and (6) wick problems have no obvious alternative solutions.[6] In terms of the traditional OODA loop, wick 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.

Research on wick—or undefined—problems suggests that a major activity of C2ISR organizations and networks will be for the stakeholders to collaboratively engage in what Allison Kidd calls *knowledge work* –the presentation of different operational views with the purpose of achieving a shared awareness and appreciation of the specific goals, constraints, threats, and opportunities developed within each perspective.[7] Achieving this common ground of understanding involves the exchange of both information and positions among the collaborating parties –a process referred to by Kjeld Schmidt as *debative cooperation*.[8] Information is exchanged primarily to increase the situation awareness of others in a bottom-up fashion, whereas positions are exchanged primarily to expand or modify the hypotheses held by others in a top-down fashion. And, while computers still offer C2ISR organizations a great information-processing capability, the wick problem environment imposes the need to consider and reconcile the variety and complexity of interpretations of information outputs generated by humans and computer systems. Such variety is necessary for deciphering—making sense of—the multiple world views of the uncertain and unpredictable future. In such an environment, the objective of a C2ISR organization is not merely to indulge in long-term planning of the future. Rather, the emphasis is on understanding the various world views that might impact the strategic and operational direction of the organization.

This need for considering and reconciling the perspectives of multiple stakeholders and experts reflects a key advantage of moving towards network-centric command and control operations. But, just as information technology does not necessarily bring about the automatic improvement of decision making performance within a single organization, so too the electronic linkage of multiple command and control organizations does not necessarily bring about automatic improvement in collaboration and the synchronization of operations. Rather, one must begin to identify and assess the various factors that influence the creation and management of actionable knowledge across a networked C2ISR system. Such factors include (1) *information technology* in the form of information displays, decision aids, and collaborative work aids; (2) *training and standards of staff performance* at both the individual and collective level, (3) *personnel management policies* as they affect levels of staff expertise and the maturity of social networks; (4) *staff process and battle rhythm* as they enable the overcoming of various technical, cognitive, social, organizational, and procedural obstacles; (5) *cultural differences* as they affect staff interactions and information exchange; and (6) *organizational design* as it facilitates and orchestrates appropriate patterns of collaboration, work flow, and decision making. Considered together, each of these factors can be said to influence the collaborative sensemaking and knowledge management activities of a networked C2ISR system in important ways.

Modeling Challenges

These aspects of defense transformation just summarized combine to produce a number of challenges for C2ISR system modelers and analysts. First, the various PMESII dimensions and interactions that characterize the battlespace imply that C2ISR decision making cannot be reduced to a simple set of attrition equations or mathematical algorithms. Rather, future C2ISR simulations should be able to explicitly reflect the manner in which various classes of available information (representing situation awareness) are interpreted and transformed into actionable knowledge and command decisions by the tacit expertise of each commander and his supporting staff of planning experts. Second, the various classes of diplomatic, information, military, and economic actions available to a joint or coalition commander imply that C2ISR decision making cannot be represented in the form of a single decision maker. Rather, future C2ISR simulations should be able to explicitly reflect decision making effectiveness and efficiency in terms of work flow and patterns of collaboration among various sets of stakeholders and experts within (or available to) each military headquarters.

Such are the challenges undertaken in the current research of the authors. Accordingly, the remainder of this paper presents a discussion of two aspects of this modeling. The first area of modeling focuses on the explicit representation of the knowledge framework (abstraction hierarchy) required for decomposing command intent into actionable knowledge within each of the PMESII dimensions of the battlespace. The second area of work focuses on the explicit representation of the staff work flow and patterns of collaboration within the various centers, working groups, cells, and teams that build this knowledge framework. Together, these representations allow the analyst to assess the influence of information technology, training, leadership, personnel management, cultural differences, and organizational design on the quality of the knowledge product (*e.g.*, Effects Tasking Order, daily Air Operations Order) emerging from the command and control process.

MODELING THE COGNITIVE FRAMEWORK OF AN EFFECTS-BASED PLANNING PROCESS

Based upon a review of relevant literature in the area of cognitive work analysis, the present research adopted the concept of Jens Rasmussen's *abstraction hierarchy* as a general framework for characterizing the knowledge product within an effects-based planning process.[9] This type of cognitive work framework allows representation of both a top-down, constructivist model of knowledge creation as well as a bottom-up positivist model of the physical battlespace. This section of the paper summarizes the key aspects of Rasmussen's abstraction hierarchy and illustrates how this concept is being used to represent the transformation of command intent into a set of specific targeting actions.

Abstraction Hierarchy: The Decomposition of Command Intent into Specific Targeting Actions

The concept of an abstraction hierarchy is but one part of the approach developed by Rasmussen and his colleagues to specify different aspects of work:

- *Work Domain*: an abstraction of the functional and physical properties of the work domain

- *Control Tasks*: a decision ladder of tasks/states that links informational inputs to output actions
- *Control Strategies*: a set of optional strategies for carrying out each level of control task
- *Social/Organizational*: a structural description of how work tasks are distributed and managed
- *Worker Competencies*: the skill, rule or knowledge-based behaviors of each control agent

As developed by Rasmussen, any work domain can be decomposed in terms of a framework called an *abstraction hierarchy*. 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. Adapted to the notion of an effects-based battlespace, 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 and Priorities* – 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.

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 2. 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.

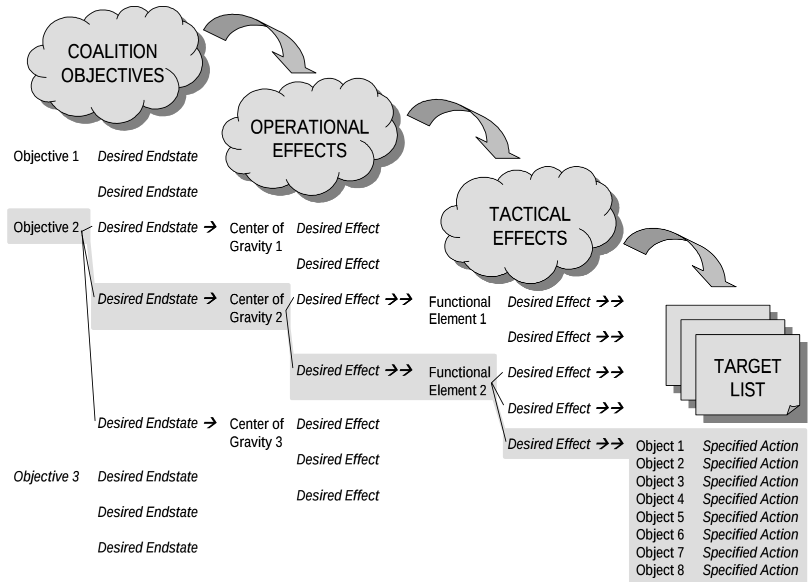

Figure 2 Development of an Abstraction Hierarchy for an Effects-Based Battlespace

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.

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 3, 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.

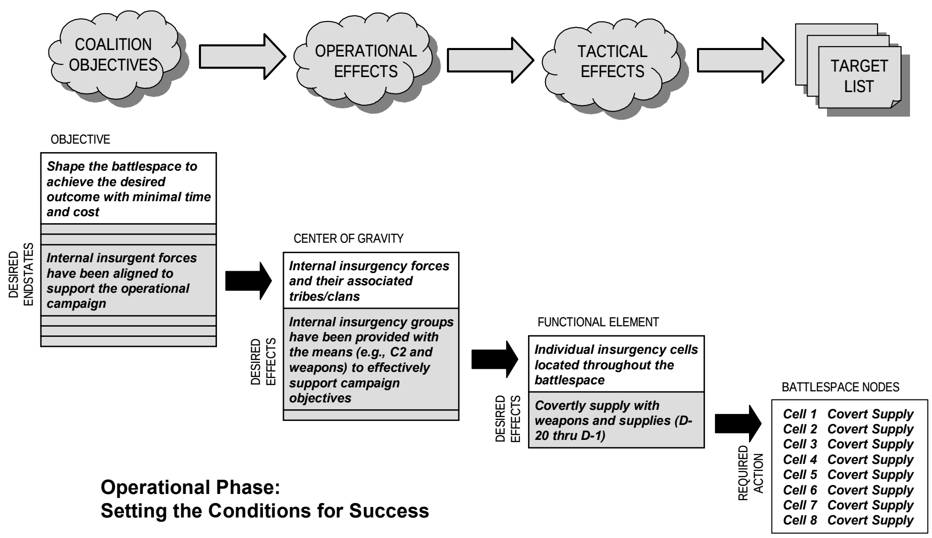

Figure 3 Example Abstraction: Setting Conditions for Success Phase

The second example (Figure 4) 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.

The final example (Figure 5) 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.

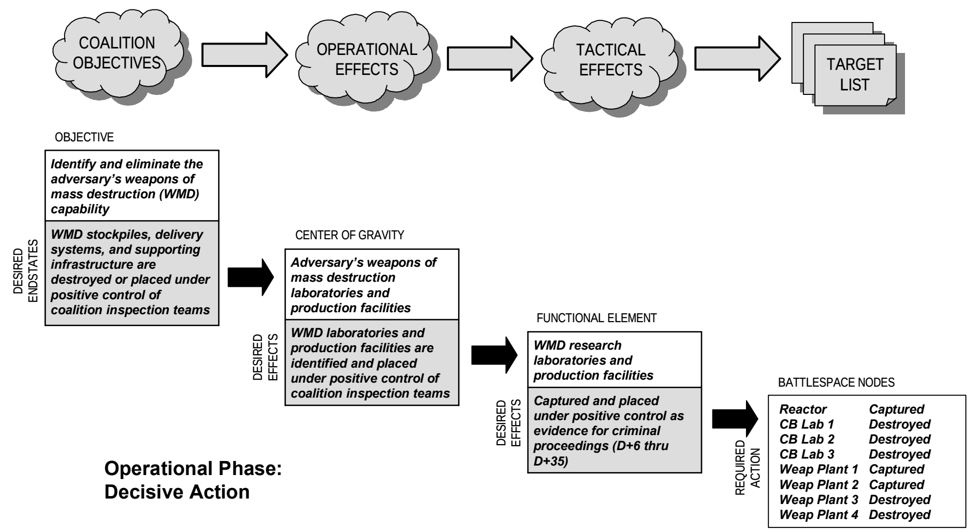

Figure 4 Example Abstraction: Decisive Action Phase

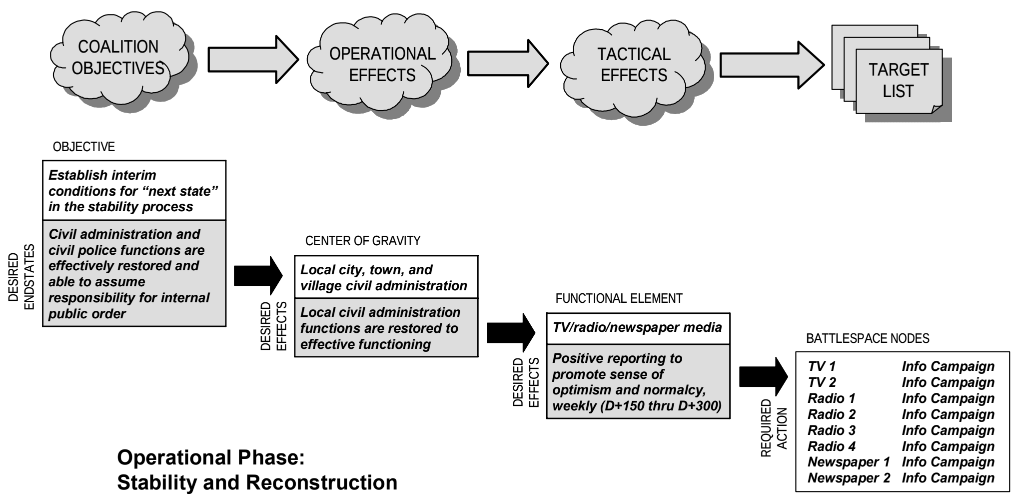

Figure 5 Example Abstraction: Stability and Reconstruction Phase

Linking Knowledge Products to Work Flow: a Nominal Joint Planning Process

Although the abstraction hierarchy framework is somewhat of a modeling artifact it reflects a means to make explicit intrinsic structural properties of work that, in this case, corresponds in a reasonable way 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 order to reflect this correspondence in a simulation model, a key element of the current research has been the analysis of cognitive work flow within various headquarters comprising a future Joint Task Force C2ISR structure. The product of this work is reflected in an overall simulation architecture that links the development of each specific knowledge product to a specific set of simulated cognitive work tasks within the model.

A portion of the nominal work flow of a notional joint planning process is illustrated in Figure 6. The work flow illustrated in this figure represents a set of operational level planning tasks that might be conducted by a Joint Task Force headquarters in collaboration with the various Component Command headquarters. [Note: A corresponding set of tactical level planning tasks has been developed but not illustrated in this paper due to space limitations.] This work flow, based on a review of draft concept documents developed by various commands and services, is considered representative of a future joint C2ISR structure. However, it is not to be construed as representing the approved plans of any specific headquarters. In fact, the simulation model is being constructed with a sufficient degree of flexibility for representing various alternative work flow configurations. In this manner, the model becomes a useful tool for exploring how a future Joint Task Force Headquarters might be synchronized (in terms of planning battle rhythm) with each of its Component Command headquarters. For example, the cognitive work tasks illustrated in Figure 6 are not rigidly tied to a specific physical location (*e.g.*, Joint Task Force Command Center). Rather, it is assumed that these tasks might be collaboratively performed at various headquarters locations utilizing the capabilities of the network to link key actors.

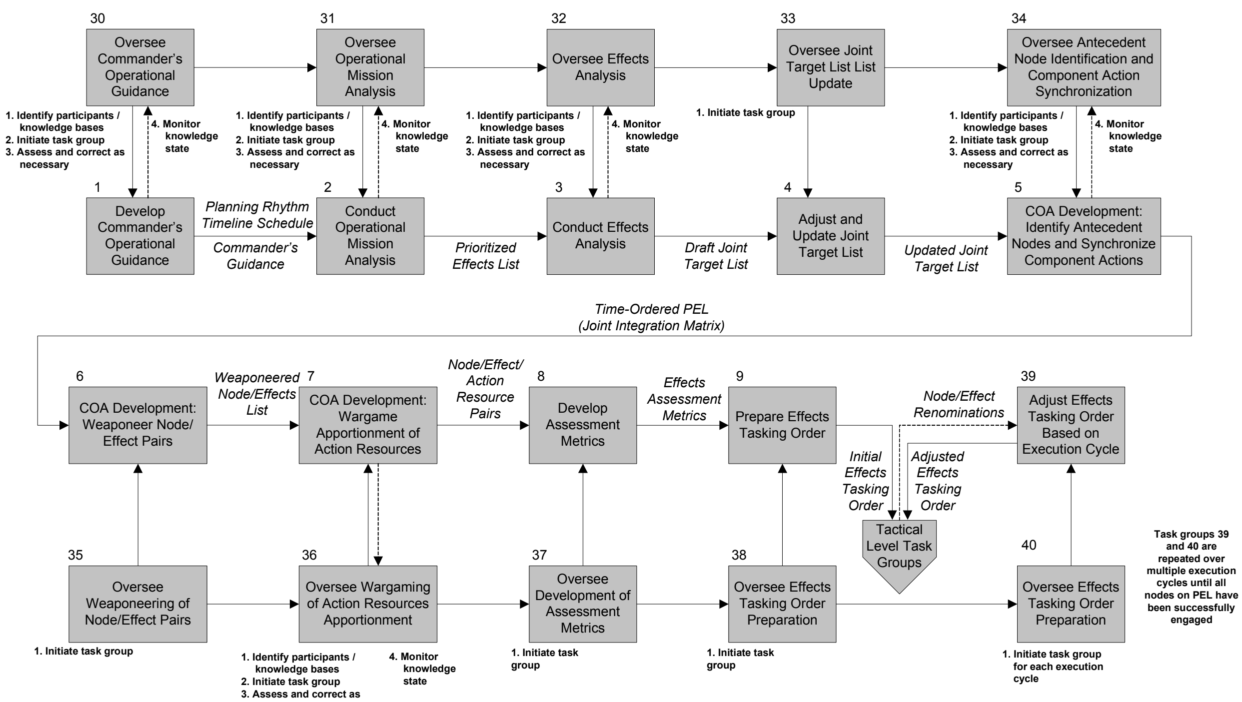

Figure 6 Example Work Flow Architecture: Operational Level Planning Tasks

As seen in Figure 6, Tasks 1-9 represent various steps in the cognitive transformation of command intent into a specific Effects Tasking Order that might be issued by a future Joint Task Force headquarters. Annotated between the tasks are the knowledge products developed at each step in the operational planning process. In terms of simulation modeling, each of the boxes shown in Figure 6 is further broken down within the architecture to reflect the various subtasks required to build each of the knowledge products. Ultimately, this architecture is represented in the form of MicroSaint© software coding that—

when executed—simulates the execution of each cognitive subtask. Noted in Figure 6 are another set of tasks that are executed in parallel with the primary planning tasks. These additional tasks represent the cognitive activities conducted by senior staff supervisors assigned the responsibility of overseeing each of the planning tasks. As will be discussed in more detail in a later section of this paper, these supervisory activities include (1) identifying the specific actors (functional experts and knowledge bases) that participate in or support a given planning task, (2) monitoring the state and quality (completeness) of the knowledge product developed by a given planning task, and (3) appropriately adjusting the areas of contributing expertise to insure the task produces an acceptable knowledge product.

MODELING THE COLLABORATIVE PROCESS OF KNOWLEDGE CREATION WITHIN A MILITARY C2ISR ORGANIZATION

The preceding discussion outlined the authors' current approach to modeling the knowledge framework (abstraction hierarchy) required for decomposing command intent into actionable targeting orders within an effects-based context. The next section of this paper summarizes the corresponding approach taken for explicitly modeling the staff work flow and patterns of collaboration that build this knowledge framework. Here, the discussion is organized around two key modeling issues: (1) the analytic portrayal of individual tacit knowledge used in the planning process and (2) the dynamic representation of staff collaboration.

Tacit Knowledge: The Constructive Interpretation of the Battlespace

A debate has existed among philosophers for centuries regarding the nature of knowledge. Early Greek philosophers such as Euclid and Socrates thought of knowledge as the development of understanding that proceeds out of logical questioning. Plato added to this concept by positing that true knowledge must be referenced to an ideal world, as opposed to the world one could apperceive through their senses. This school of philosophy—known as *rationalism*—argues that knowledge is derived primarily through logical reasoning without reference to empirical observation. Rationalism is reflected in the development of both language and mathematics, and is seen to strongly influence the fields of computer science and artificial intelligence. Centuries later, Sir Francis Bacon would counter the school of rationalism by arguing—in his *Novum Organum* of 1620—that knowledge should be based on empirical observation. Other British philosophers of this period, Thomas Hobbes and John Locke, would modify Bacon's extreme position of *empiricism* by arguing that a certain degree of human rationalism is necessary to organize general facts and observations into theories and laws.

Moving to the early 20th century, Bertrand Russell, another British philosopher and major contributor to mathematical logic, further refined these positions by hypothesizing that knowledge is attained through two principal means: acquisition and description. Of these two methods, description accounts for the larger portion of a person's knowledge –an argument that places emphasis on the formal elements of language that could be logically combined to produce truths or contradictions. Russell's arguments thus led to yet another school called *analytic philosophy* which claims that knowledge should be built upon *logical positivism*, or its more extreme form of *logical atomism*. In these various forms, analytic philosophy has come to dominate much of science, particularly within English-speaking countries. Inherent in this definition of knowledge are several ideas that researchers—particularly in the physical sciences—have come to accept without question: (1) knowledge is based on the accumulation of "facts" and analytic "descriptions," (2) these facts and descriptions are said to possess universal properties that are independent of situation and individual viewpoint, and (3) knowledge can be logically built or unfolded through the processes of induction and decomposition, respectively. A classic example of analytic philosophy can be seen in the definition of information fusion developed by the Joint Directors of Laboratories and popularized within the military community.[10] This definition, in its most naïve form, defines knowledge as being built in a bottom-up fashion from empirical observations, to the identification of battlespace entities and tracks (Level 1), to the fusing of spatial and temporal patterns into an adversary's order of battle (Level 2), to the inference of adversary intentions and potential threats (Level 3). Such a definition, however, is somewhat vague and has led to numerous attempts to produce a more workable definition of knowledge creation.[11] Nevertheless, the underlying assumptions about knowledge creation reflected this type of bottom-up, analytical philosophy paradigm has permeated much of the thinking within the C2ISR modeling and simulation world. Such an approach presumes that knowledge creation can be reduced to algorithmic computations and automated by machine technology –thus placing little or no emphasis on the role of human experience and expertise in the knowledge creation process. Moreover, the universality of knowledge implied by the analytic philosophy leaves little opportunity for examining the factors that influence knowledge creation within a wick problem context where each stakeholder or expert might view the operational situation from a different perspective.

To properly reflect the role of human experience and expertise within the simulation of a C2ISR system, particularly within the wick problem context of 4th-generation warfare, one must consider a number of philosophical movements that arose within the 20th century to challenge the analytic philosophy position. Here, the work of several different philosophers is found to be useful. First, we consider the writings of Sir Karl Popper, a British philosopher of the early and middle 20th century, whose most significant contribution was the argument that true science must be based on the notion of falsifiability. Underlying this work was Popper's belief that knowledge grows by trial and error, that knowledge creation is both a rational and creative process, involving elements such as traditional beliefs, criticism, logic, imagination and experimental trials. Additionally, Popper sought to reconcile the objective nature of the physical world with the subjective nature of the internal mental world of individuals.[12] Here, he offered the metaphor of three worlds of knowledge as a framework for understanding the complex nature of knowledge: (1) *World One* represents the world of physics, rocks, trees, and physical fields of forces; (2) *World Two* represents the psychological world of feelings, dispositions to act, and all kinds of subjective experiences; whereas (3) World Three reflects the external products of the human mind such as values, theories, books, and institutions. In C2ISR modeling terms, World One reflects the physical entities of the battlespace. World Two reflects the subjective views and expertise of a commander and his staff. World Three contains the externalized products of human thinking—command intent, intelligence assessments, operations orders, Common Operating Picture—that are used to communicate beliefs and intentionality among individuals and organizations.

Other challenges to analytic philosophy are seen in the writings of Thomas Kuhn, the team of Edward Sapir and Benjamin Whorf, George Kelley, and Michael Polanyi. In his 1962 *The Structure of Scientific Revolutions*, Kuhn argued that a scientific community cannot practice its trade without some set of received beliefs.[13] These beliefs provide the framework for conducting acceptable research within the community –they establish the boundaries for what may be studied; what types of variables, assumptions, and methods may be used; and what conceptual paradigms and theories are accepted as relevant. As the process continues, the growth of knowledge and understanding within a given conceptual framework eventually reaches the point of diminished returns over time. As this point is reached, some researchers will begin to question the boundaries of the established scientific framework by considering new variables, new assumptions, new methods, and new conceptual paradigms. This refocusing of science to examine an area of investigation from a new perspective was defined by Kuhn as a *paradigm shift* –a point of discontinuity where the scientific community brings in a new set of foundational beliefs to frame the search for new knowledge.

A second challenge is found in the field of psycholinguistics, the study of language and how it relates to the formation of meaning and understanding within a community or society. Of specific note in this area is the work of linguist and anthropologist Edward Sapir and his student and colleague Benjamin Whorf. The resulting *Sapir-Whorf Hypothesis*, developed in the early 20th century, reflected two key ideas: linguistic determinism and linguistic relativity.[14] Linguistic determinism states that there is a systematic relationship between the grammatical categories of the language a person speaks and how that person uniquely conceptualizes the world. Linguistic relativity states that people who use different languages will conceive of the world differently. A similar challenge comes from George Kelly—an engineer who later became a clinical psychologist—who began to notice that different people can often hold quite different and unique conceptions of the world around them. As part of his theory of personality, Kelly posited that each individual acts as a scientist –that from the dawn of consciousness, we each try to make sense of the world as we experience it, and we do this by constantly forming, testing, and refining hypotheses about the world.[15] By the time an individual reaches adulthood, the person has developed a very complex model of the world and their place in it. Kelly defined this phenomenon in terms of *personal constructs*, an individual's organization of unique mental models of the world that are both shaped by prior experience and are used to interpret new experiences. Core constructs were further defined by Kelly as those deeply-held values and principles that are unlikely to change when the individual is faced with contradictory information.

As a final challenge to analytic philosophy, we consider the work of Michael Polanyi, a Hungarian medical scientist whose main work was in the field of physical chemistry prior to turning to philosophy. Collected in 1958 as part of his major work, *Personal Knowledge: Towards a Post Critical Epistemology*, his writings introduced the concept of tacit knowledge –knowledge that is intuitive and cannot be fully expressed in verbal form.[16] Polanyi's concept of tacit knowledge was reflected in three main theses: (1) true discovery cannot be accounted for by a set of articulated rules or algorithms; (2) while knowledge is public, it is also to a very great extent personal or constructed by humans; and (3) the knowledge that underlies explicit knowledge is more fundamental. Polanyi saw new experiences as always being assimilated through the concepts that the individual disposes and which the individual has inherited from other users of the language. Those concepts are tacitly based and form the background for all thinking. In each activity of thinking, there are two different levels or dimensions of knowledge involved that are complementary and mutually exclusive: *focal knowledge* (knowledge about the object, problem, or phenomenon that is in focus) and *tacit knowledge* (background knowledge that serves as a tool for improving what is in focus).

Representing Tacit Knowledge within the Planning Process

One of the key elements in the current modeling research is the representation of tacit knowledge employed within a joint planning process. Of specific interest in this regard is the tacit knowledge that specific sets of actors bring to the type of work flow tasks outlined in Figure 6. Of course, representing tacit knowledge in analytic form reflects somewhat of a paradox since tacit knowledge, by definition, cannot be easily expressed in explicit form. Consequently, a generalized method or paradigm was sought for approximating the impact that an actor's tacit knowledge might have on the transformation of input cues into a knowledge product for any given cognitive task in the joint planning process. One such paradigm is the Leontief *input-output matrix*, originally developed by the Nobel economist, Wassily Leontief, as a method for relating resource inputs to commerce outputs within the American economy.[17] As originally conceived by Leontief, his model relating n inputs to m outputs consisted of an $n \times m$ matrix of transformation coefficients. Each of the vertical columns of n coefficients represents the combined contribution of a single unit of each resource input to one of the m commercial outputs.

Adapting this paradigm to the concept of knowledge creation, the Leontief input-output matrix serves as a method for approximating the elements of knowledge created from a specific set of input cues. In Leontief's original work, his matrix of coefficients ignores the complex, interactive workings of a national economy. Rather, the entire process is approximated by a linear model. In similar fashion, use of this matrix for modeling the development of knowledge outputs within a given cognitive task summaries the complex, interactive workings of human memory and is able to avoid the cost of explicitly addressing the low level nonlinearities of complex cognitive work. In this way the linear modeling approach is able to reflect the manner in which a set of cognitive task inputs give rise to a set of output associations that constitute the knowledge product of a specific step in the planning process. Given the similarity of form of many of these tasks, the input-output matrix can be generalized across many of the tasks represented in the simulated work flow of a joint planning process. Figure 7 illustrates the adaptation of the Leontief input-output matrix in the current modeling research.

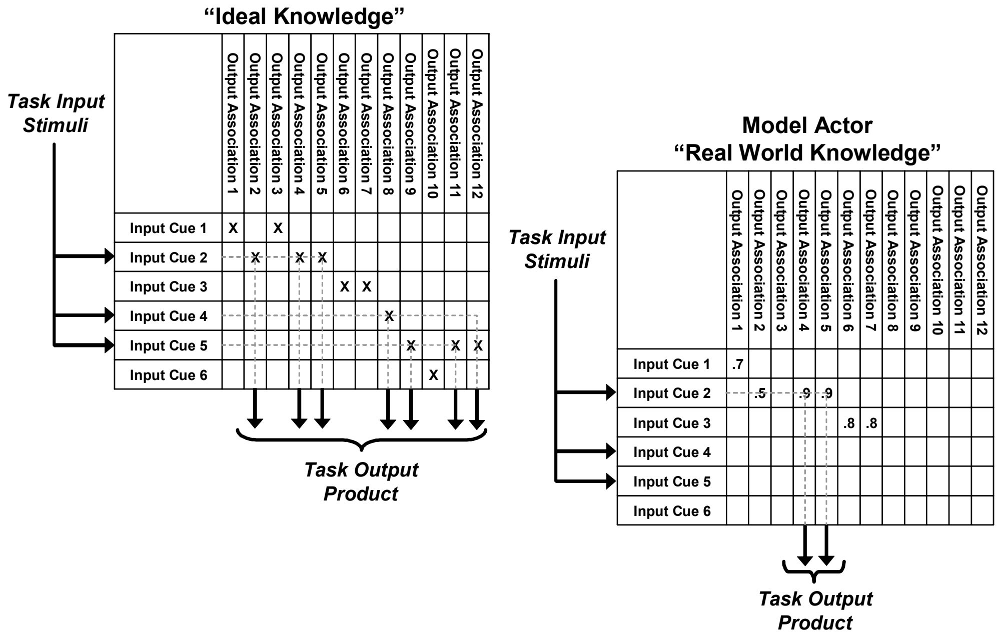

Figure 7 Leontief Input-Output Matrices Depicting the Creation of Knowledge Products from a Set of Input Cues

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. Ideal knowledge corresponds to Popper's World Three of Knowledge –*i.e.*, it reflects what a modeling and simulation community might collectively agree upon regarding ground truth in a specific military scenario. 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. In this manner, the matrix on the left represents the ideal performance standard for a given step in the planning process.

By contrast, the matrix at the right of this figure reflects the knowledge of a specific staff actor[1] 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 appropriately 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. In a similar fashion, false positives could be included in the matrix to reflect noise or erroneous associations by a particular staff actor. 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

[1] 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.

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 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.

Collaboration: The Reconciliation of Tacit Knowledge Differences among a Set of Actors

Operational and tactical planning within a joint C2ISR system is a collaborative process and reflects one of the inherent values of a network-centric organization. Collaboration is also necessary whenever an organization faces a wick problem environment.[18] Accordingly, many of the work flow tasks simulated within the current modeling effort area considered to be performed in collaborative fashion by a specific set of actors (functional experts and knowledge bases). As a theoretical basis for this modeling, the current research considers two areas of work in the knowledge management literature. 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. Nonaka and Takeuchi view organizations as amplifiers of individual knowledge.[19] Rather than focusing on knowledge transfer, they emphasize the process by which teams and organizations continuously create new knowledge –a process referred to as "*chishiki keiei*". That is, organizations serve to amplify the knowledge created by individuals and crystallize it as part of the knowledge network of the organization. Two types of activity drive this process of amplification: (1) the conversion of tacit knowledge into explicit knowledge and (2) the movement of knowledge from the individual level to the team, organizational, and inter-organizational levels.

The knowledge amplifier paradigm is expressed through a specific set of structures and a specific set of activities. Structurally, Nonaka and Takeuchi define organizations in terms of three levels: *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 military headquarters context, explicit knowledge includes the Common Operating Picture as well as plans, briefings, and other information available from the organization's intranet. 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 topmost layer consists of ad hoc *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. Project teams are led by middle managers within the organization who serve to translate command visions into concrete operations.

As defined by Nonaka and Takeuchi, all three levels 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 ad hoc project teams toward useful and purposeful goals, and for synchronizing their knowledge products into cohesive decisions and actions. At the topmost level, 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. The paradigm outlined by Nonaka and Takeuchi illustrates a basic tension between (1) the traditional—predictable and cyclical—military decision making process defined during the industrial age and (2) a more dynamic, agile, and self-organizing decision making process argued by various futurists. The spontaneous formation of ad hoc project teams provides a headquarters with the agility needed to cope with the complexities and dynamics of future military operations. On the other hand, without some type of business system—*i.e.*, battle rhythm—in place, there exists nothing to insure proper focus and synchronization of these ad hoc knowledge creation activities into cohesive and purposeful action. Thus, a military C2ISR organization must reflect a proper balance between the predictable/cyclical and the emergent/nonlinear.

The second area of research is that of Thomas Davenport and Laurence Prusak who reflect a western epistemological tradition –one that views teams and organizations in mechanistic ways and sees them as a marketplace for sharing information and knowledge.[20] For the team or organization to make appropriate and timely decisions, the marketplace must support the appropriate and timely sharing and distribution of knowledge. A marketplace consists of 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 wick 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. Finally, *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.

In addition, Davenport and Prusak identify several obstacles or "frictions" within a team or organization that can inhibit the transfer of knowledge:

- Lack of trust (immature relationships 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 incentive for sharing);
- Lack of absorptive capacity in recipients (inadequate training, narrow-mindedness);
- Belief that knowledge is prerogative of specific groups (parochialism, not-invented-here); and
- Intolerance for mistakes or need for help (failure to recognize that errors and learning are a normal part of the organizational process).

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).

For the modeler, the marketplace paradigm of Davenport and Prusak suggest several relevant aspects of C2ISR performance that should be reflected or represented in a simulation model. First, the effectiveness of a team or organization as a knowledge marketplace is reflected in the degree to which available tacit experience and expertise is linked to action –that is, the degree to which knowledge buyers and sellers are brought together in ways that are (1) appropriate for the evolving problem space and (2) timely for enabling effective decision making and action taking. Second, the effectiveness of a team or organization is reflected in the degree to which it minimizes or eliminates each of the specific obstacles or "frictions" identified by Davenport and Prusak.

Representing Collaboration in the Planning Process

In order to capture the various ideas just discussed, the current research sought to reflect the manner in which a headquarters might organize its available functional expertise into meaningful project teams for each step in a future joint planning process. Consequently, a cognitive task analysis was conducted utilizing draft documentation available from various commands[2] in order to construct a tentative picture of how such collaboration might be organized[3]. Identified from this analysis was a set of boards, working groups, teams, and centers that each (1) include specific personnel membership from across the different military headquarters elements and (2) have assigned responsibility for conducting specific cognitive steps in the joint planning process. Such an analysis provides the tentative basis for assigning specific staff actors (each possessing a unique body of tacit knowledge) to participate in the various tasks simulated within a joint C2ISR organization. Within this same framework, it also becomes possible to reflect various types of technological, cognitive, social, and organizational obstacles or "frictions" that affect each community of practice within such an organization. An illustration of the overall approach taken for representing collaboration in a specific headquarters is illustrated in Figure 8.

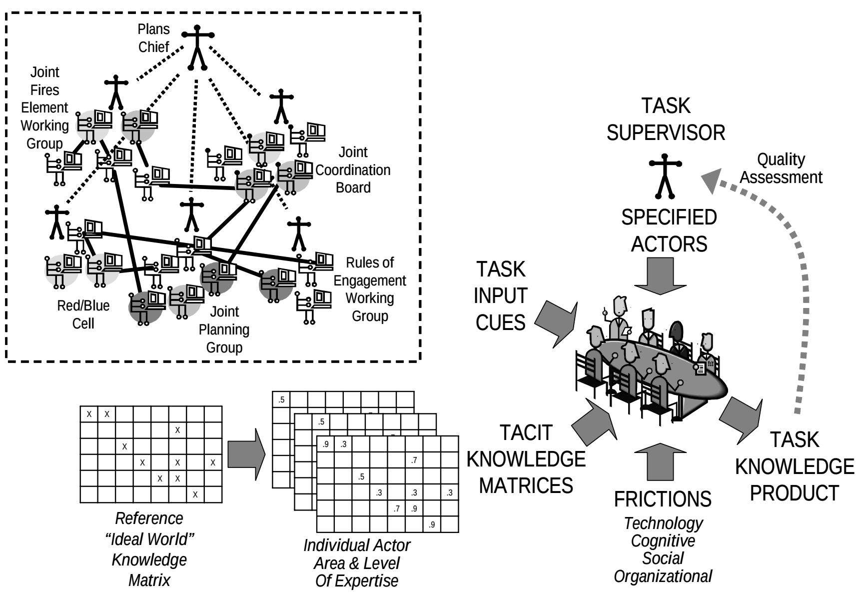

Figure 8 The Representation of Collaborative Knowledge Creation

[2] Draft documentation specifically addressed proposed organizational structures, battle rhythms, staff procedures, and personnel manning for various future headquarters and command centers. The ideas extracted from these documents were interpreted to be notional representations for modeling purposes only, and not the approved policies of any specific military command.

[3] Of course, the focus, scope and even existence of different working groups, boards, etc. can be used as variables in the model, as well. Thus, the impact of different knowledge, or the lack thereof, derivable from dynamically formed "knowledge groups" can easily be assessed within our modeling framework.

As depicted in the upper left corner of Figure 8, the modeling architecture presumes that the various boards, working groups, teams, and centers within a headquarters will be assigned responsibility for conducting specific steps or tasks within the planning process. Knowledge products then flow among these various communities of practice according to the overall battle rhythm established within the headquarters. The collaboration process occurring within each of these tasks is depicted on the lower right side of Figure 8. For each task, a specific supervisor actor (acting as a knowledge broker) is assigned to identify the other actors (knowledge sellers and knowledge buyers) that will functionally participate in the task. Associated with each of these identified actors is a unique tacit knowledge matrix that reflects the area and level of expertise of that actor vis-à-vis the task demands. Additionally specified are any technological, cognitive, social, or organizational barriers (frictions) that serve to diminish or deny each actor's participation in the given task. The modeling logic then computes a *group outcome matrix* that reflects the reconciliation and integration of the various individual tacit knowledge matrices of the participating actors. The group outcome matrix is computed according to one of four collaboration schemes specified by the modeler:

- *Authoritative*: The ranking actor's association probability values are used wherever a difference exists among the participating actors.
- *Inclusive*: The maximum value of each association probability is used from across the set of participating actors.
- *Democratic*: The unweighted average of each association probability across the set of participating actors is used.
- *Hybrid*: A rank-weighted average of each association probability across the set of participating actors is used, where rank is specified as a model input.

The group outcome matrix is then used along with the input cues provided for the task to generate the cognitive associations that comprise the different elements of the knowledge product created by the task.

DIMENSIONS OF C2ISR SYSTEM PERFORMANCE

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 9. 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.

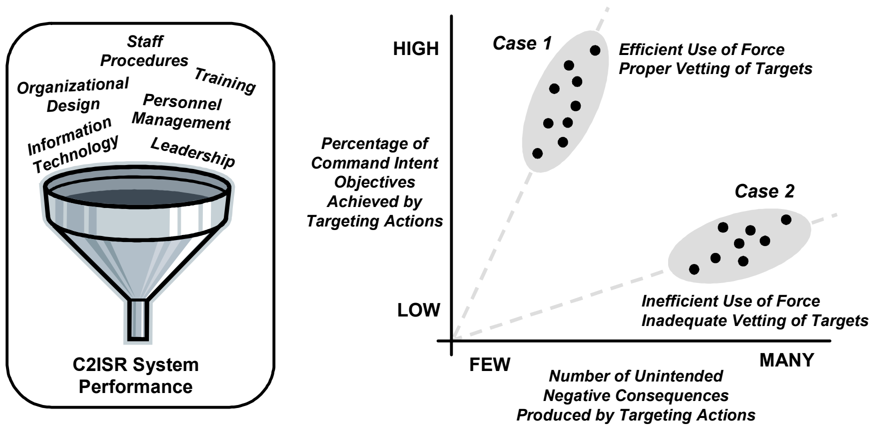

Figure 9 Dimensions of C2ISR System Performance

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 wick 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[21]. 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 approximating the cognitive process by which the tacit knowledge matrices of different actors is used in combination to produce a task knowledge product. 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.

Modeling should always be undertaken with a clear understanding of the types of the types of metrics used for assessing system performance. 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.

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THE SIMULATION OF SENSEMAKING AND KNOWLEDGE MANAGEMENT WITHIN A JOINT EFFECTS-BASED PLANNING SYSTEM

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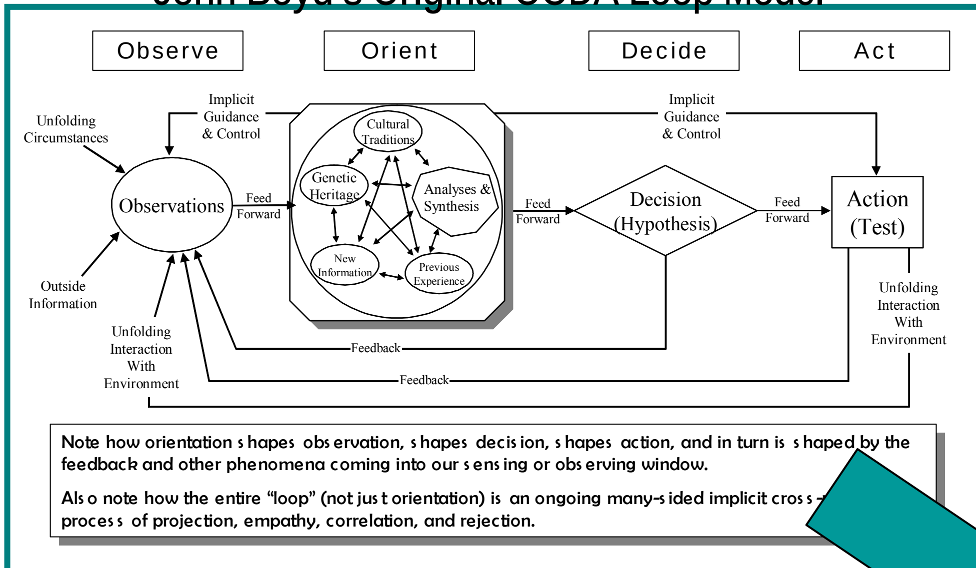
Research Goal: Explicit Simulation of Knowledge Creation within a Joint C2ISR System

John Boyd's Original OODA Loop Model



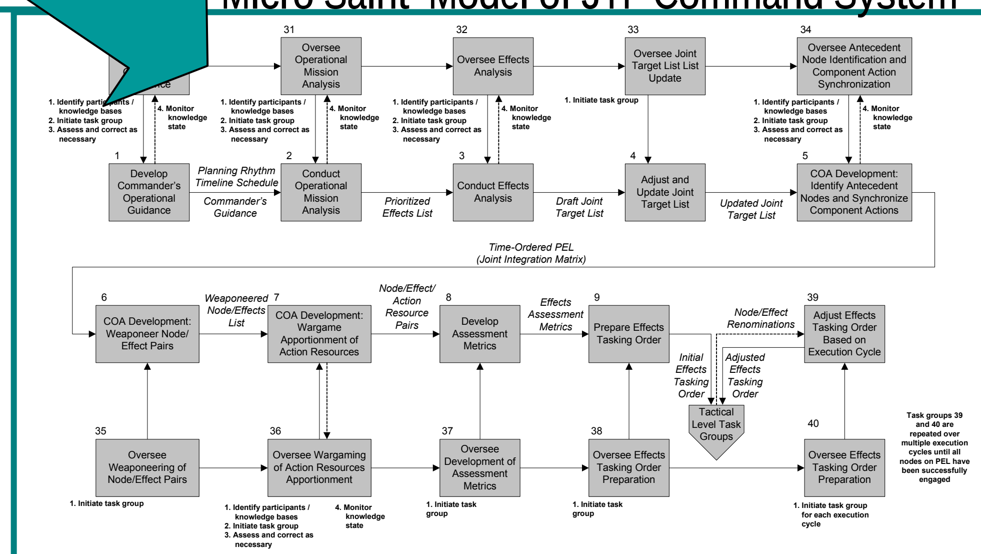
Knowledge Creation

- Represent joint operational planning in terms of a hierarchical framework of abstracted knowledge elements
- Represent the tacit knowledge and expertise of the staff in terms of associational input-output matrices

Staff Collaboration

- Link staff workflows and collaboration patterns with the development of specific knowledge products
- Reflect the influence of technology, training, leadership, and organizational design on collaboration effectiveness

Micro Saint Model of JTF Command System



4^{th}-Generation Warfare

Mao Tse-Tung

Ho Chi Minh

FSLN / Sandinista

Intifada / PLO

Unique elements of 4^{th}-generation warfare…

- Strategic goal: *Defeat our political will* to engage in a region
- Strategy: Pursue *political, economic, and social actions*, engaging in limited military operations only when it furthers strategic interests *(create impression of intractable struggle)*

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

Implications for design of C2ISR functionality…

- Adversary is coalition of convergent interests, rather than single nation state
  →*Identify and disrupt critical linkages that hold coalition together*
- Adversary coalition consists of several tiers: leaders, supporters, civilian interests
  →*Employ different approach to disrupting or manipulating each tier*
- Multiple, overlapping networks exists across political, social, economic, religious, humanitarian, and military dimensions
  →*Understand the role, structure, and processes of each type of network*
- Strategic objectives are accomplished through direct C^2, economic/social disruption, intimidation of specific individuals/groups, and exploitation of emergent situations
  →*Identify and influence fitness conditions, rather than severing commo links*

Multiple Dimensions of Knowledge Space

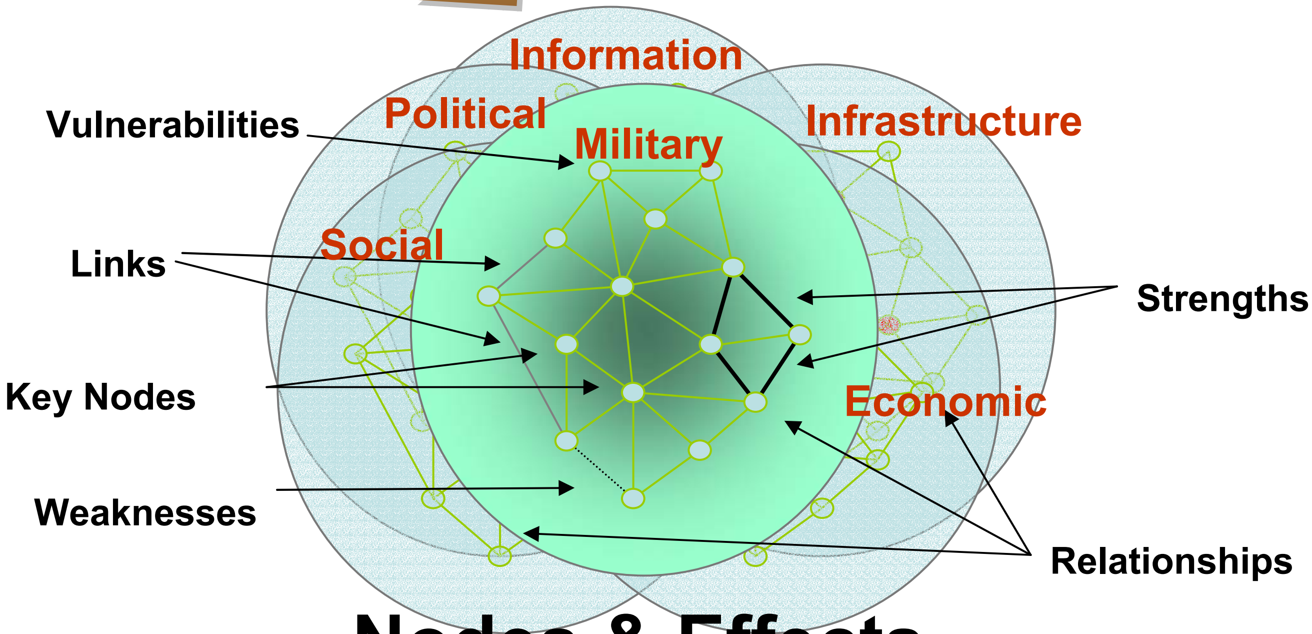
DIME Actions

- **D**IPLOMATIC
- **I**NFORMATION
- **M**ILITARY
- **E**CONOMIC

Effects-Based Operations

Functional Dimensions of the Battlespace

- **P** Political
- **M** Military
- **E** Economic
- **S** Social
- **I** Information
- **I** Infrastructure



Nodes & Effects

Enactment of a Wicked Environment

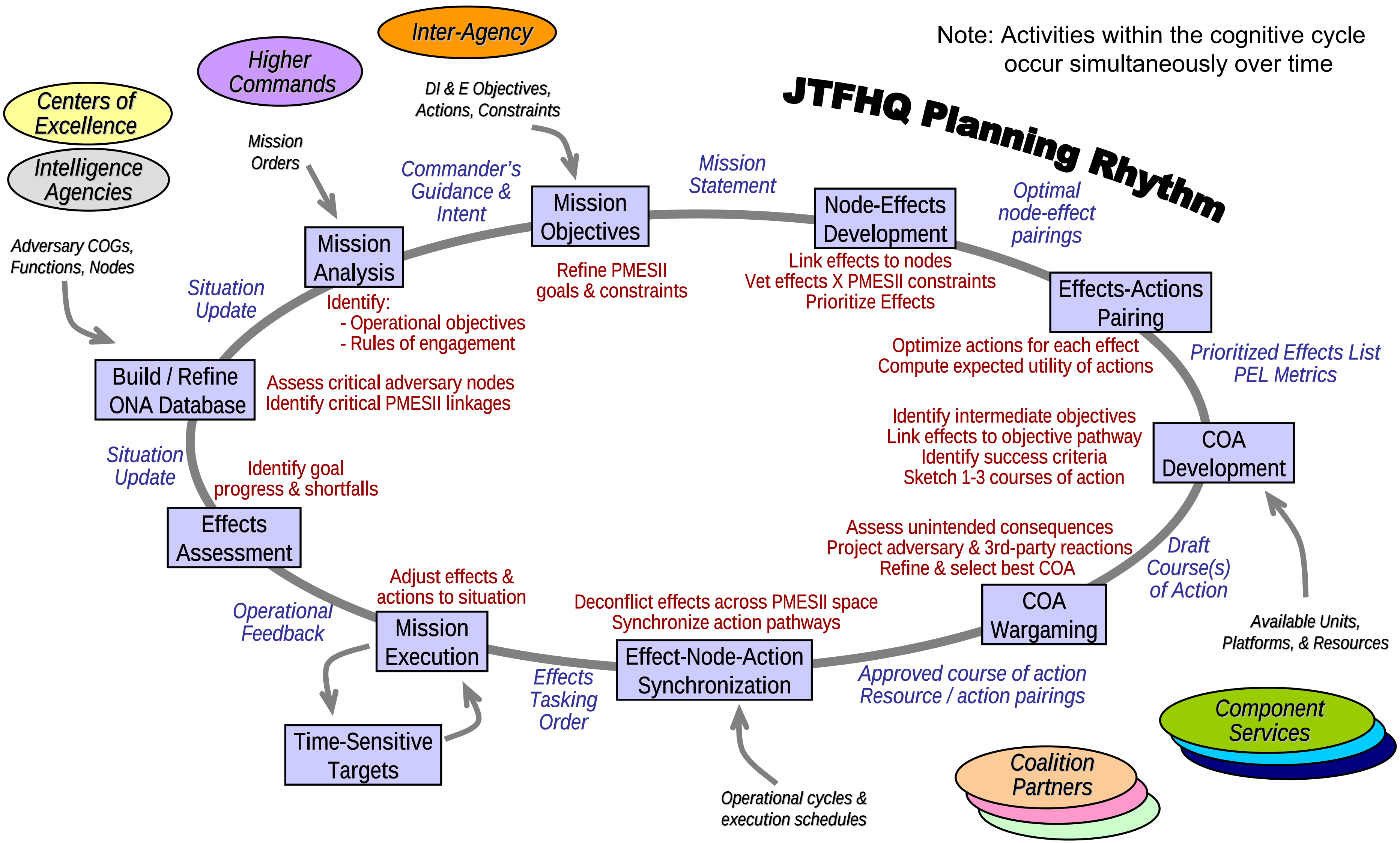
Wicked problem environment…

- Problem space is ill-structured
- No “right” solution, only “good enough”
- Problem-solving ends only when you run out of resources
- Unique/novel set of conditions and factors
- No second opportunities to do it again
- No obvious alternative solution

Sensemaking driven by action…

- Clarify/prioritize goals and constraints
- Characterize battlespace relative to these goals/constraints
- Identify key dimensions and variables predictive of cause/effect relationships
- Identify key obstacles to success
- Build solution paths to overcome obstacles

Future Joint Planning Rhythm (*Notional)

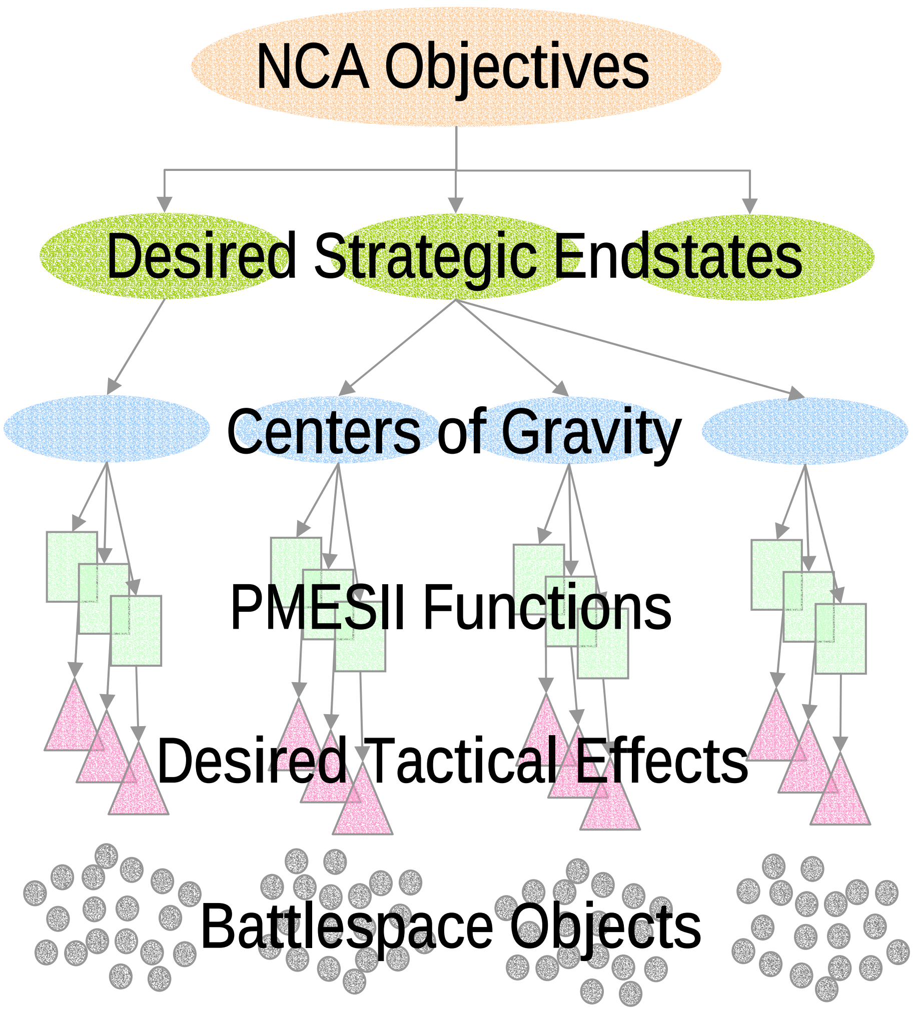


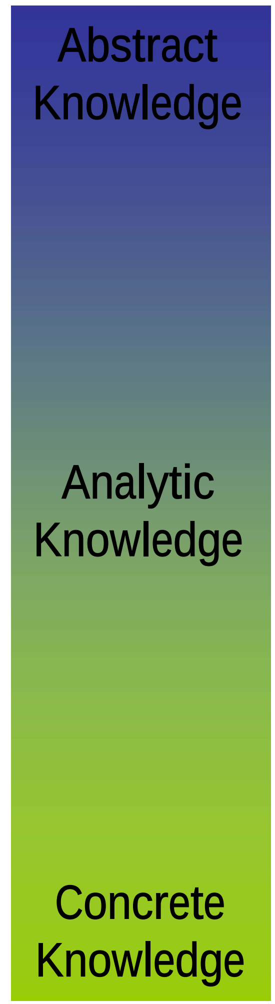
Modeling Challenges

1. Representing the Sensemaking Framework of an Effects-Based Planning Process
2. Modeling the Collaborative Process of Knowledge Creation within an Effects-Based Planning Process
3. Defining the Relevant Dimensions of C2ISR System Performance

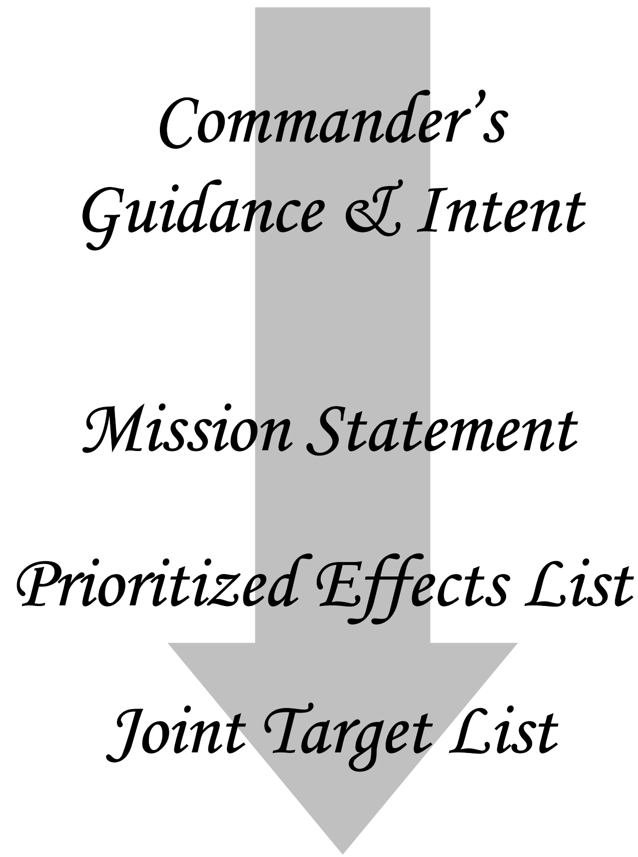
Decomposition of an Effects-Based Knowledge Space

Abstraction Hierarchy

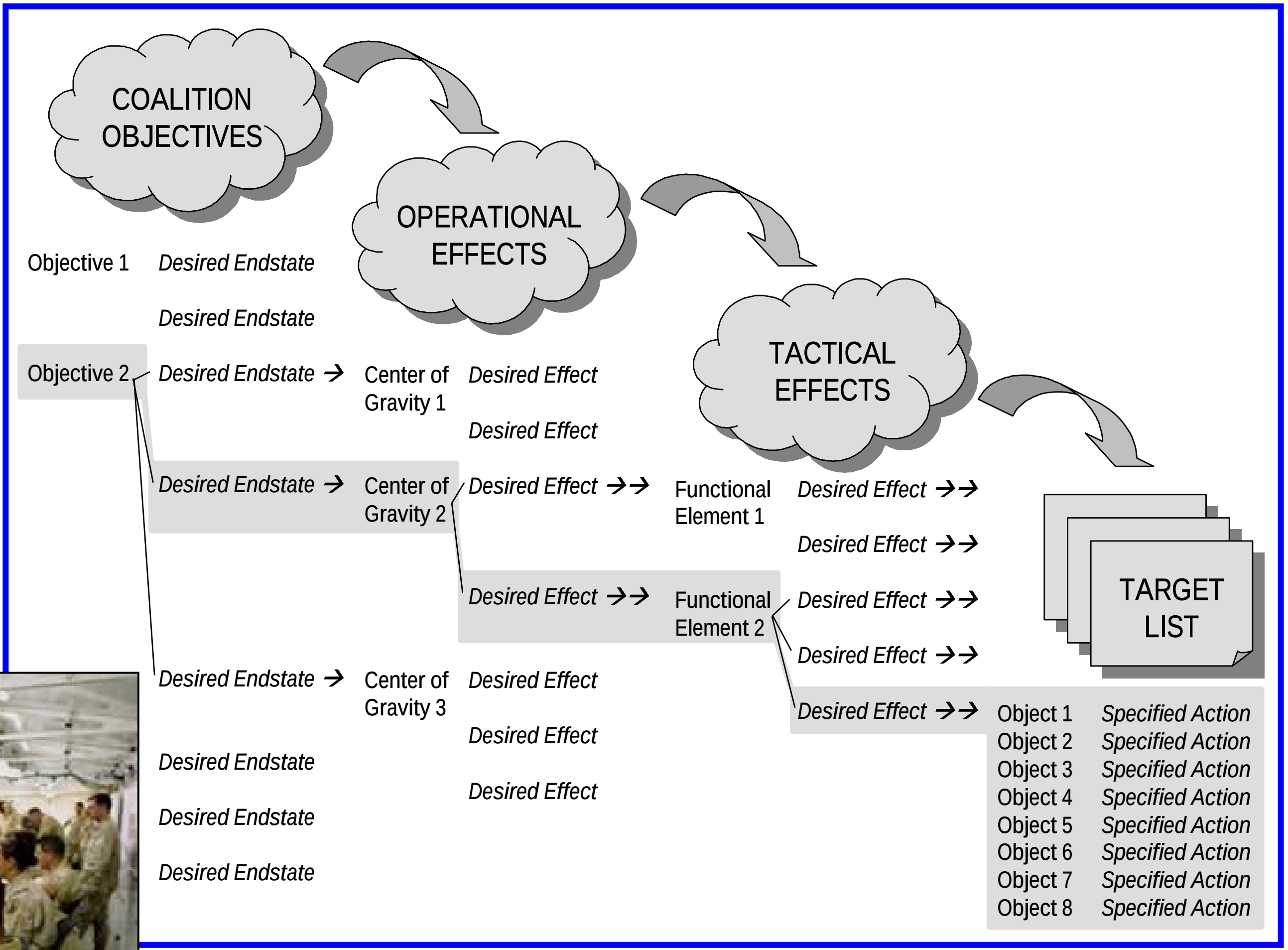




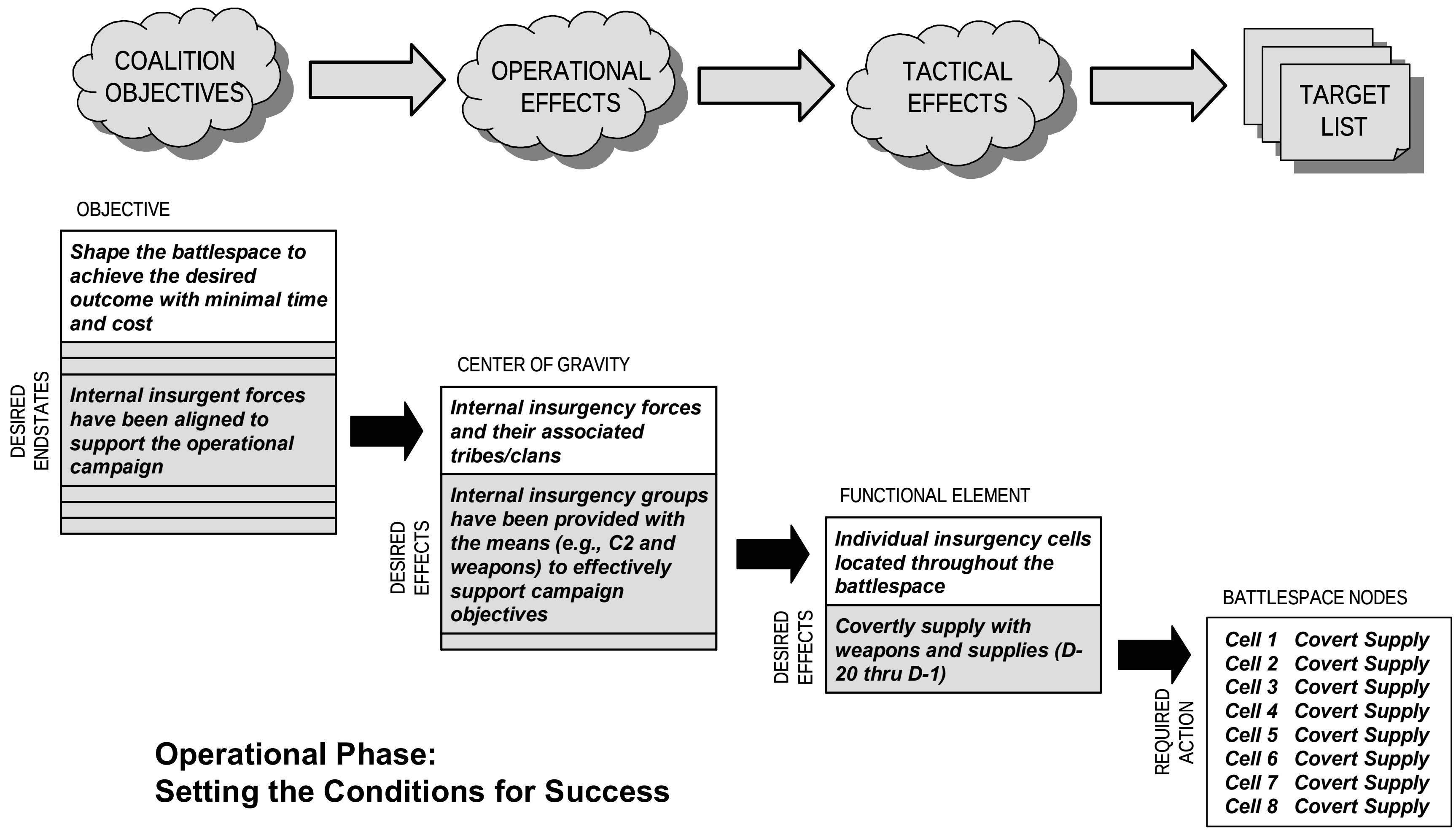
Corresponding Knowledge Products



Knowledge Elements within an Effects-Based Operational Plan

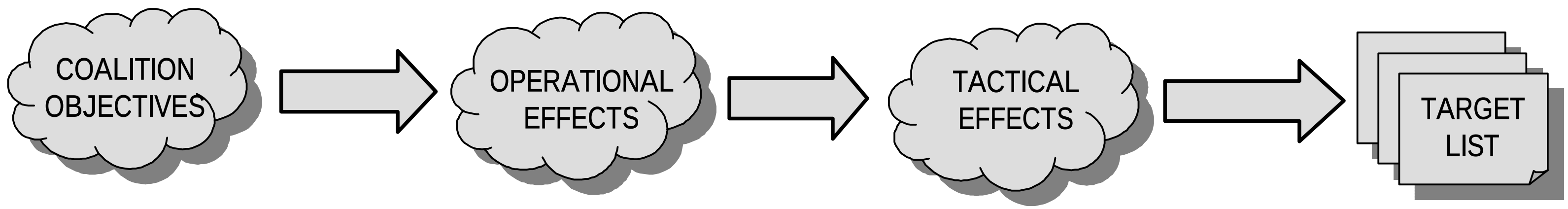


Example #1: Setting Conditions



Operational Phase:
Setting the Conditions for Success

Example #2: Stability and Reconstruction



OBJECTIVE

Establish interim conditions for "next state" in the stability process

DESIRED ENDSTATES

Civil administration and civil police functions are effectively restored and able to assume responsibility for internal public order

CENTER OF GRAVITY

Local city, town, and village civil administration

DESIRED EFFECTS

Local civil administration functions are restored to effective functioning

FUNCTIONAL ELEMENT

TV/radio/newspaper media

DESIRED EFFECTS

Positive reporting to promote sense of optimism and normalcy, weekly (D+150 thru D+300)

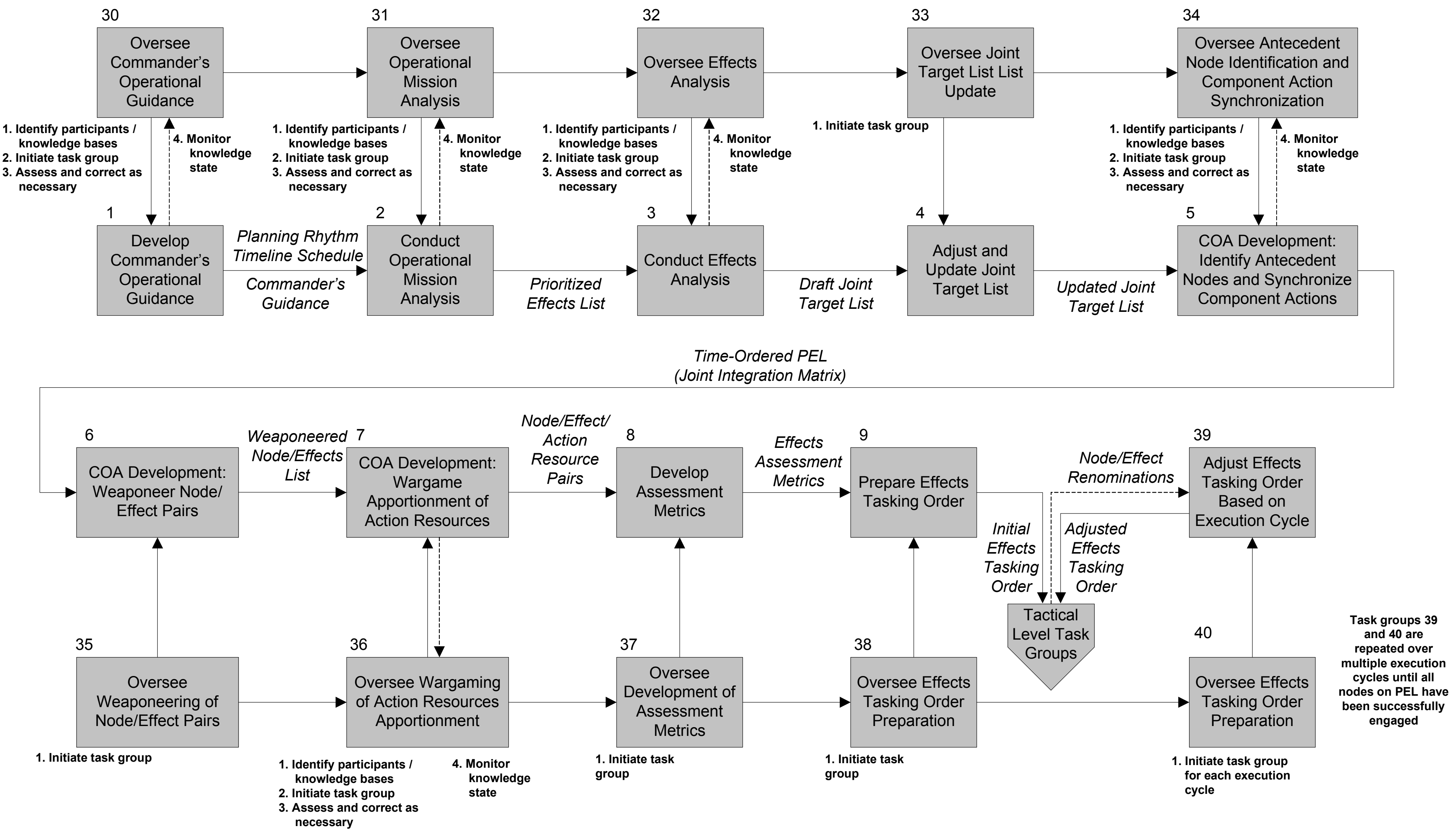
BATTLESPACE NODES

REQUIRED ACTION

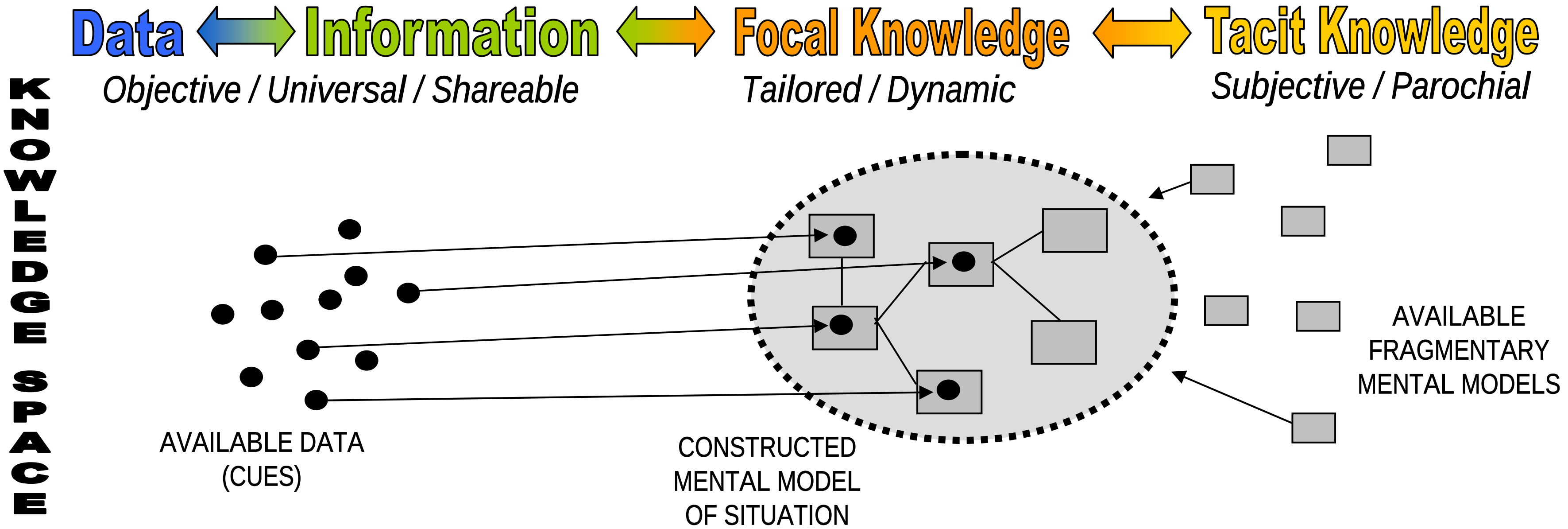
TV 1	***Info Campaign***
TV 2	***Info Campaign***
Radio 1	***Info Campaign***
Radio 2	***Info Campaign***
Radio 3	***Info Campaign***
Radio 4	***Info Campaign***
Newspaper 1	***Info Campaign***
Newspaper 2	***Info Campaign***

Operational Phase:
Stability and Reconstruction

Linking Knowledge Products with Staff Workflow



Data/Frame Model of Individual Sensemaking



Sieck, W.R.; Klein, G.; Peluso, D.A.; Smith, J.L. & Harris-Thompson, D. (2004). *FOCUS: A Model of Sensemaking*. Fairborn, OH: Klein Associates, Inc.

Representing Individual Tacit Knowledge

"Ideal Knowledge"

Task Input Stimuli

	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		

Task Output Product

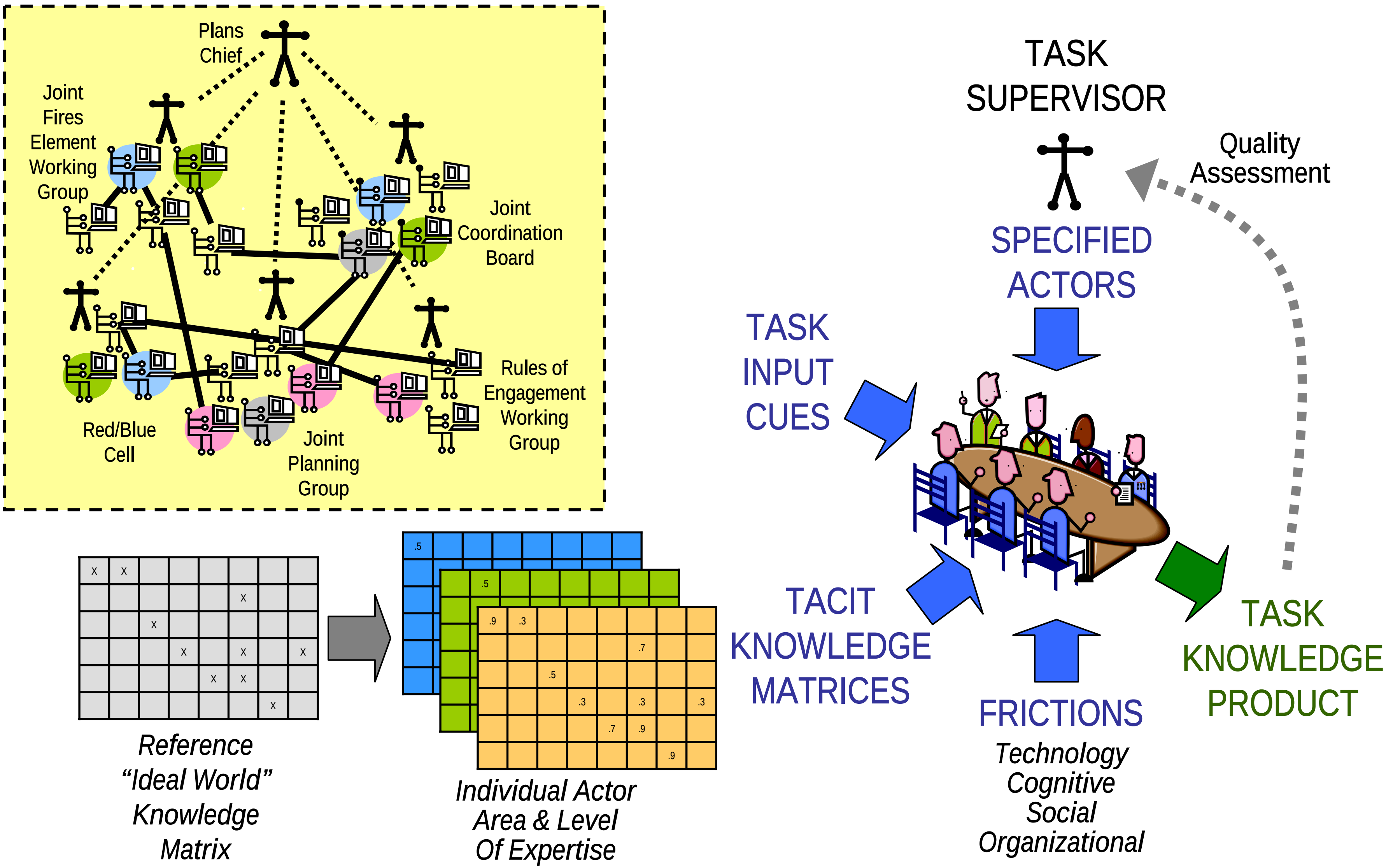
Model Actor
"Real World Knowledge"

Task Input Stimuli

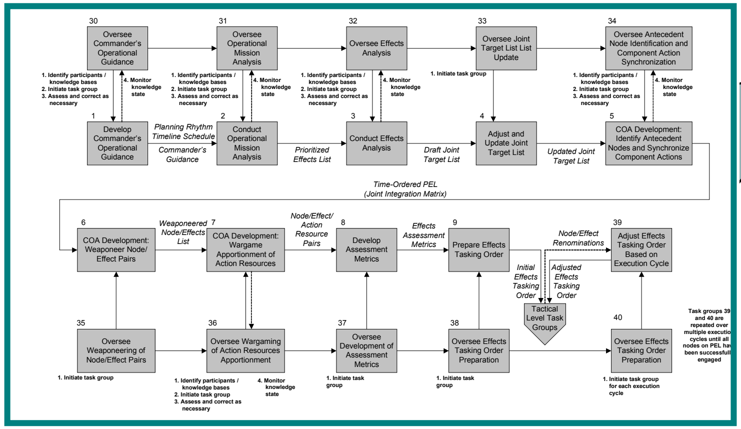
	Output Association 1	Output Association 2	Output Association 3	Output Association 4	Output Association 5	Output Association 6	Output Association 7	Output Association 8	Output Association 9	Output Association 10	Output Association 11	Output Association 12
Input Cue 1	.7											
Input Cue 2		.5		.9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

Task Output Product

Collaborative Integration of Tacit Knowledge



Command Intent → Joint Prioritized Target List



ACTIONABLE KNOWLEDGE STATE

COALITION OBJECTIVES

1110101

Collaborative Output of Knowledge Association Task

DESIRED ENDSTATES

1111100110011

Collaborative Output of Knowledge Association Task

CENTERS OF GRAVITY

1111110011100011

Collaborative Output of Knowledge Association and Vetting Tasks

FUNCTIONAL ELEMENTS

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Collaborative Output of Knowledge Association, Vetting, 2nd-Order Effects, and Antecedent Tasks

NODES / MISSION PACKAGES

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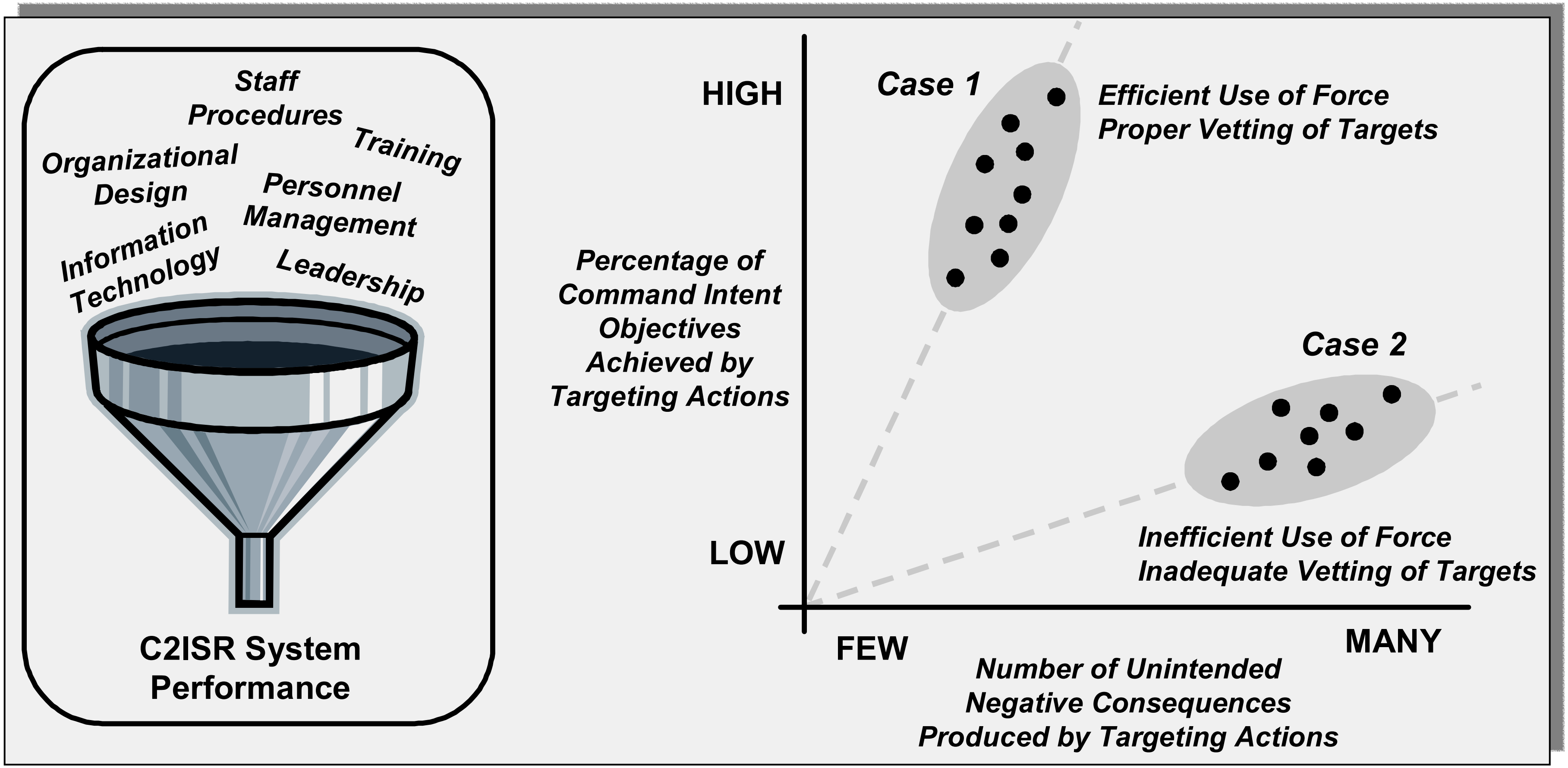
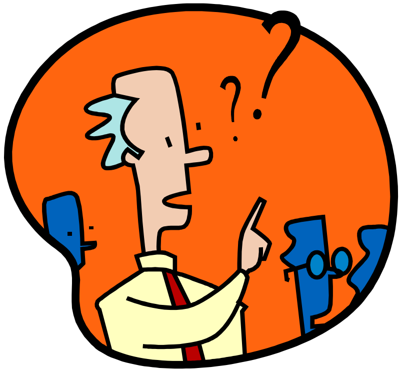
C2ISR System Performance



Summary

- This AFRL-funded project shifts the focus of C2ISR modeling from information collection / management to sensemaking and knowledge creation
- This shift of modeling focus is motivated by the advent of 4th generation warfare and effects-based operations
- The approach is well-grounded in the socio-cognitive literature
- Key aspects of this modeling approach include
  - The explicit representation of knowledge elements that reflect the decomposition of command intent into prioritized targeting actions
  - The linkage of cognitive work flow and collaboration patterns with the effective (or ineffective) creation of these knowledge elements



QUESTIONS ?