C4ISR Assessment: Past, Present, and Future

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Abstract

The paper begins with a look at the past – a historical perspective on how C4ISR assessment evolved. Prior to 1970, national security assessments generally neglected C4ISR issues. This paper describes the changes that took place thirty years ago, which entailed a basic re-engineering of the C4ISR assessment process. This involved fundamental changes in community culture, organizations, education, processes, resources, tools, research and development, and products. This initial period of innovative C4ISR assessments was followed by a hiatus in the late 1980s as the Department of Defense (DoD) leadership lost interest in C4ISR assessments.

The paper then transitions to the present period of C4ISR assessment. This renaissance began in the early 1990s, due in large part to profound changes in the international geopolitical environment. In response to these challenges, important advances have been made in the areas of C4ISR assessment processes and tools. Many of these advances are encapsulated in the NATO Code of Best Practice (COBP) for C2 Assessment. The paper briefly summarizes the key elements of the COBP.

The paper concludes by turning to the future of C4ISR assessment. It summarizes several recent advances and identifies several key changes that are making the C4ISR assessment problem even more challenging.

A. Introduction

The assessment of C4ISR systems in support of military operations is an art form that has evolved substantially over the last thirty years. Prior to that period, national security assessments were generally insensitive to C4ISR system issues. C4ISR systems supporting military operations were typically addressed in one of three ways: they were assumed to be "perfect" (e.g., they provided perfect information with no time delays); they were considered as a second or third order effect; or they were ignored. When they were considered they were often treated as a "patch" (e.g., introduced in Lanchester's equations in an effort to reflect the influence of imperfect C4ISR systems).

Thirty years ago that approach to assessing C4ISR systems in support of military operations began to change. That transformation required a basic re-engineering of the assessment process. It involved changes in culture, organizations, people, processes, resources, tools, research and development (R&D), and products. The second section of this paper ("the past") identifies key elements in each of these categories and discusses the consequences of these changes.

This initial period of innovative assessments of C4ISR systems had a brief hiatus during the latter part of the 1980's. At that stage, the leadership in the Department of Defense (DoD) manifested reduced interest in the assessment of C4ISR systems. Budgets for military systems (including C4ISR systems) were at historically high levels and the emphasis in the Pentagon was on the acquisition (vice the assessment) of these systems. This attitude began to change in the early 1990's. The catalyst for this change was the profound alteration of the international scene. The USSR and the Warsaw Pact dissolved and Desert Shield/Desert Storm provided an insight into the role that innovative C4ISR systems could play in support of contemporary warfare. During the remainder of the 1990's, a new national security context arose and with it, a new set of challenges in assessing C4ISR systems in support of military operations. In response to these key challenges, a new appreciation of the C4ISR assessment process emerged. Many of these thoughts are captured in the NATO Code of Best Practice (COBP) for C2 Assessment (Reference 1) and its subsequent revision (Reference 2). Those products, which are the result of the deliberations of representatives from ten NATO nations over a multi-year period, encapsulate principles and insights on the assessment of C4ISR systems in the context of conventional conflict and operations other than war (OOTW). The third section of this paper ("the present") summarizes the major features of those documents.

Although the state of the art in assessing C4ISR systems in support of military operations has advanced considerably over the last thirty years, there are several residual C4ISR assessment challenges as we look to the future. The final chapter of this paper ("the future") concludes with a brief discussion of those challenges and the initiatives that are underway to address them.

B. The Past

In the mid-1970s a confluence of factors emerged that changed fundamentally the way that the assessments of C4ISR systems in support of military operations are performed.

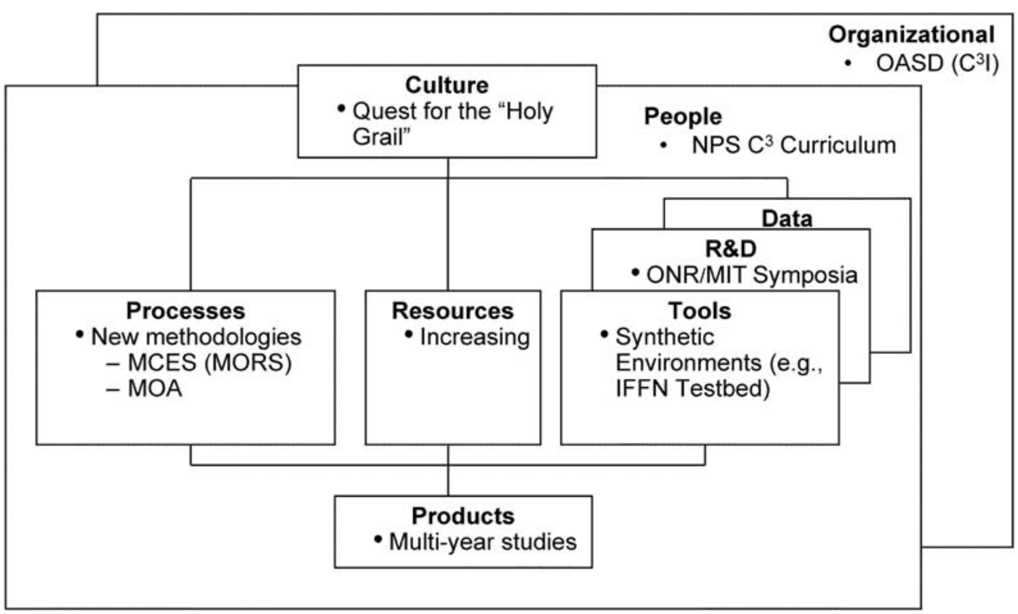

Figure 1. "Awakening" (1975 - 1985): A Business Process Re-engineering Perspective

Figure 1 identifies those broad factors and key events associated with them. The major stimulus for these events lay in the cultural change that was provided by key civilian and military leaders in the defense community. These included, *inter alia*, Robert Hermann Harry Van Trees, Charles Zraket, and Major General Jasper Welch. They launched a crusade for a "holy grail" –- the ability to assess the impact of command and control systems on force effectiveness (Reference 3). Their actions were motivated by the intellectual curiosity of these individuals, the emerging awareness of the importance of C4ISR systems in modern warfare, and the need to justify the budgets for C4ISR systems to a skeptical Congress.

Organizationally, this initiative was facilitated by the creation of the office of the Assistant Secretary of Defense for C3I. This action brought together the fragmented organizations within the Office of the Secretary of Defense (OSD) that were responsible for command and control, communications, intelligence, and defense support systems (e.g., electronic warfare, navigation). Second, the Naval Postgraduate School (NPS) established a C3 curriculum that helped to create the human capital needed to assess C4ISR systems. Finally, the Office of Naval Research (ONR) established a multi-year program with MIT to pursue R&D in support of C4ISR system assessment. In the latter case, the principals were innovators in the field of optimal control systems. Although the optimal control paradigm proved to have limited applicability to the major issues associated with C4ISR systems, it did prove of value in addressing a subset of important issues (e.g., the multi-sensor, multi-target fusion problem). In addition, it gave rise to a vibrant community of interest that acquired a shared understanding of the nature of the problem.

As a consequence of these factors, a variety of new methodologies emerged for assessing C4ISR system utility. One key intellectual thread emerged from a sequence of workshops sponsored by the Military Operations Research Society (MORS). They gave rise to the Modular Command and Control Evaluation Structure (MCES) that established a framework for defining and evaluating relevant Measures of Merit (MoMs) for assessing C4ISR systems (Reference 4). That framework was subsequently adapted and extended by the NATO COBP (see below for a further discussion). A second important development occurred with the formulation and application of the Mission Oriented Approach (MOA) to C2 assessment (Reference 5**)**. The MOA revolves around the addressing of four questions:

- What are you trying to achieve operationally?
- How are you trying to achieve the operational mission?
- What technical capability is needed to support the operational mission?
- How is the technical job to be accomplished?

This approach emphasizes that it is important to evaluate C4ISR systems within the context of the missions that they are to support. The approach is implemented by employing a top-down decomposition linking missions, functions, tasks, and systems. One of the major residual challenges remains the "roll up" process by which the analyst assesses the extent to which mission objectives are satisfied by proposed packages of C4ISR systems.

At this time it was recognized that one of the key dimensions of C4ISR system assessment concerns the performance of distributed teams of individuals under stress. To address that dimension, interest arose in the creation of manned simulator testbeds that subsumed the weapons systems and C4ISR systems that support a specific mission. An early example of such a testbed is the Theater Air Command and Control Simulation Facility (TACCSF) (originally named the Identification Friend Foe or Neutral (IFFN) Testbed), which brings together teams of operators manning simulated weapons systems (e.g., airborne interceptors, high to medium range air defense systems) and associated C4ISR systems (e.g., AWACS, associated ground based C2 systems) (Reference 6)**.** These testbeds provide a flexible tool for assessing the full range of doctrine, organization, training, material, leadership and education, personnel, and facilities (DOTML-PF) associated with proposed C4ISR system options. In addition, recent advances in computer science (e.g., the creation of the High Level Architecture (HLA) **(**Reference 7)) have greatly facilitated the development and evolution of these virtual simulations.

Drawing on these elements, studies began to emerge that provided logical, systematic linkages between packages of C4ISR systems and overall mission effectiveness. An early example of these products was developed as part of the NATO C3 Pilot Program (Reference 8) in support of the Tri-Major NATO Commanders (MNC) C3 Master Plan.

During the latter half of the 1980s, there was a noticeable decline in interest in addressing the issues associated with the assessment of C4ISR. This was attributable, in part, to the high budgets that were available to acquire DoD systems and the attitudes of the senior DoD leadership. Many adopted the mantra "paralysis through analysis!" and focused on the issues associated with acquiring systems. The lack of interest in assessment, in general, was manifested by the reduced influence of DoD's analysis organizations (e.g., the Weapons System Evaluation Group (WSEG) was disestablished; the seniority of leaders of OSD and Service analysis organizations was reduced and they had significantly less impact on the decisionmaking process).

In the early 1990s the attitude towards C4ISR assessment underwent a profound change. This change was triggered by cataclysmic changes in the geopolitical environment (e.g., the dissolution of the USSR and the Warsaw Pact) and the lessons learned from operations such as Desert Storm where advances in C4ISR had a major affect on operations (e.g., the use of GPS to support navigation over featureless terrain; the use of JSTARS to detect concentrations of adversary armor). The perceived effectiveness of precision, standoff weapons, enabled by C4ISR, stimulated the formulation of new paradigms for warfare (e.g., the revolution in military affairs (RMA)).

Consistent with these conceptual changes, many organizational changes were enacted to improve the assessment of military analysis, in general, and C4ISR assessment, in particular. These included the creation of the Defense Modeling and Simulation Office (DMSO), to champion the creation and use of M&S in support of education & training, assessment, operational support, and acquisition; the revitalization of the Command and Control Research Program (CCRP), to stimulate C2 R&D; the initiation of the Joint Analysis Model Improvement Program (JAMIP) to create, in part, new simulations that represented the effects of C4ISR more accurately and credibly; and the creation of new organizations to perform C4ISR assessments (i.e., the C4ISR Decision Support Center (DSC)) and to assess C4ISR prototypes (e.g., the Joint C4ISR Battle Center (JBC)). More recently, the J-9 organization in Joint Forces Command (JFCOM) was created to champion joint experimentation. High on their priority list has been experiments to deal with theater level C4ISR issues.

These organizations began to produce C4ISR assessments that helped senior DoD decision makers address challenging C4ISR issues (e.g., the C4ISR Mission Assessment (CMA) in support of the 1997 Quadrennial Defense Review). In addition, professional societies, such as MORS, convened workshops that identified and explored key challenges in M&S (e.g., Simulation Technology (SIMTECH) 2007 (Reference 9)) and C4ISR assessment (e.g., C4ISR Assessment for 2010 (Reference 10)).

C. The Present

In the mid-1990s, NATO Panel 7 established Research Study Group – 19 (RSG – 19) to develop a COBP for assessing Command and Control in the context of conventional conflict. That product was ultimately issued under the aegis of the newly formed NATO Studies, Analysis, & Simulations (SAS) Panel (SAS-002) (Reference 1). Subsequently, NATO SAS-026 was established to extend the COBP to include the assessment of C2 in the context of OOTW (Reference 2).

Figure 2 provides an overview of the major elements of an effective C4ISR system assessment that are identified in the initial version of the NATO COBP. This figure highlights the major steps that should be performed in the assessment and the products that should be developed during that process. However, it was determined in the follow-on activity (NATO SAS-026) that

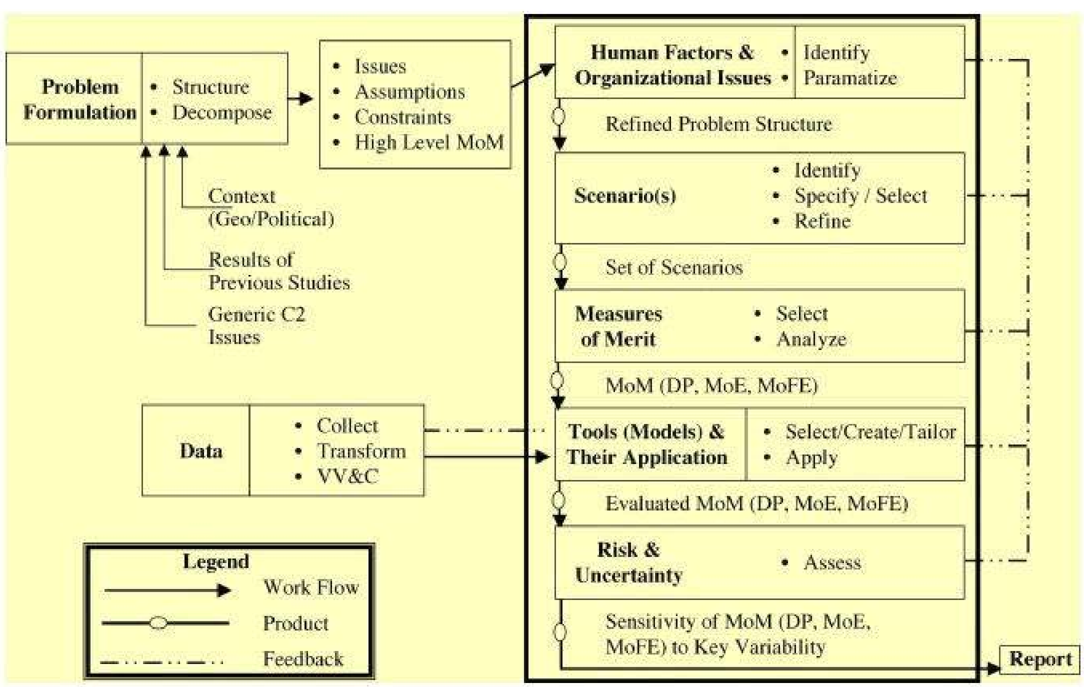

Figure 2. NATO COBP C2 Assessment Process (Original)

a meaningful assessment of C4ISR systems will rarely follow this linear process. Recent experience has demonstrated the need to tailor and implement a non-linear process that iterates among these elements in a fashion that reflects the nature of the problem at hand. Thus, it was decided to recast this central figure to emphasize the non-linear, iterative nature of the C4ISR assessment process (see Figure 3). The following discussion is broadly keyed to this latter framework.

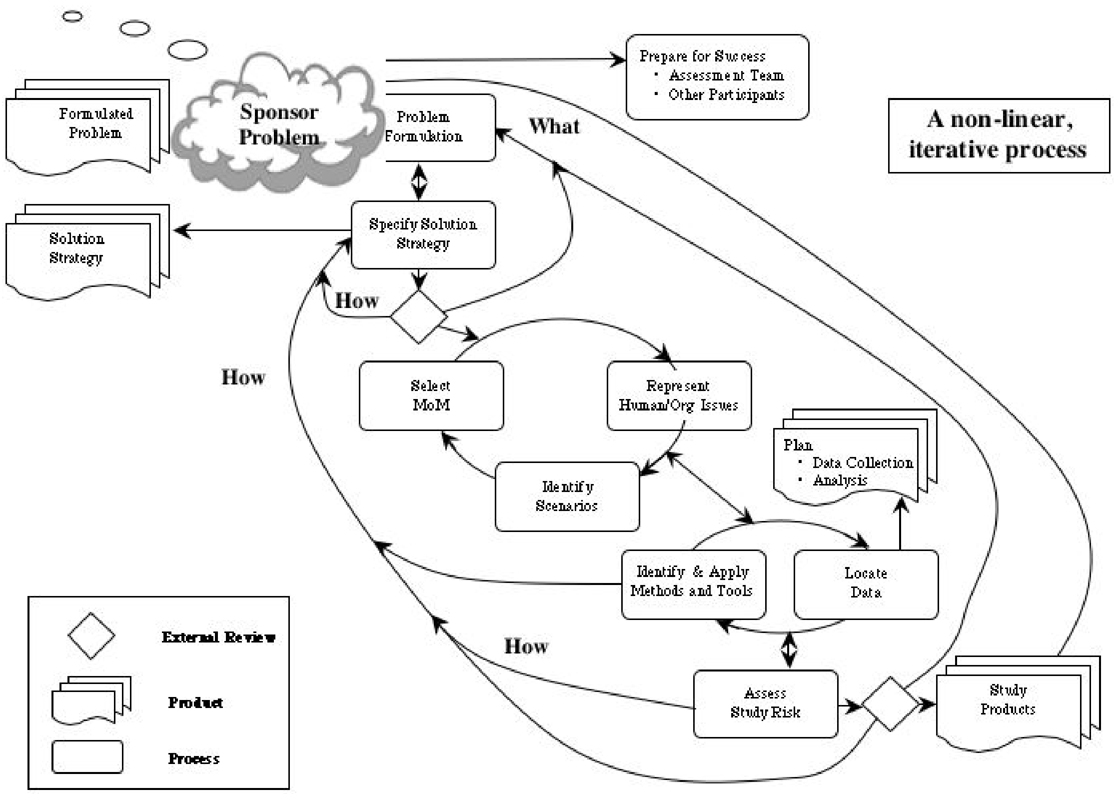

Figure 3. NATO COBP C2 Assessment Process (Revised)

• ***Prepare for Success.*** As an initial step, the individuals who are involved in a C4ISR assessment must be identified, the relationships among the participants must be understood, and a common understanding of the study's goals, objectives, scope, and administrative aspects must be established and documented. The scope of such an undertaking almost always requires an interdisciplinary team. This includes (but is generally not limited to) individuals skilled in operations research, modeling and simulation, C4ISR systems, and operations. It is rare that a single individual would have the requisite skills and depth of knowledge required to perform such an assessment. In addition, in the extension of the COBP to OOTW it was noted that it is important to incorporate individuals skilled in the social sciences (e.g., political science, demography).

Furthermore, the relationship among the assessment team, the key sponsor, and the other stakeholders is of paramount importance and will influence the course and success of the effort.

To build and sustain this relationship, Terms of References should be agreed to along with a common language and study glossary. The latter can be of particular importance in the arcane world of C4ISR.

• ***Problem Formulation.*** The basic purpose of this phase of the assessment is to clarify "what" is to be achieved. In general, C4ISR system problems involve complex, poorly defined issues that are difficult to formulate sharply. This is particularly true of assessments associated with OOTW where it is vital to understand the context for the operation (e.g., relevant culture and history). Consequently, extreme care must be taken in structuring and decomposing the problem. In most C4ISR system assessments, it is exceptionally difficult to subdivide the problem into manageable segments that can be analyzed substantively, the results of which are amenable to meaningful synthesis to shed light on the original, larger problem. This is exacerbated by the fact that it is rarely acceptable to pose options strictly in materiel terms. For issues associated with the transformation of the DoD, options must be cast in the context of all of the dimensions of DOTML-PF. At the conclusion of this phase of the assessment, it is vital that the assessment team and the study sponsor agree on the "real" issues of interest.

• ***Solution Strategies.*** The purpose of this phase of the assessment is to transform the understanding of "what" is to be achieved into "how" those goals and objectives are to be realized. It must produce a meta-plan (subsuming, *inter alia,* plans for analysis, data collection, review) that addresses all of the key phases of the assessment process (i.e., MoMs, relevant human and organizational factors, specification of scenarios, data collection requirements, and methods and tools to be used in the analysis). Case studies of the process suggest that a simple linear path through these key phases is rarely successful; it generally warrants an iterative, non-linear treatment of these issues before the plan converges.

• ***Measures of Merit.*** The NATO COBP states that no single measure exists that satisfactorily allows the assessment of either the overall effectiveness or the performance of C4ISR systems. Drawing on the work of prior MORS workshops (References 4, 11), a multilevel hierarchy of measures of merit was recommended (see Figure 4).

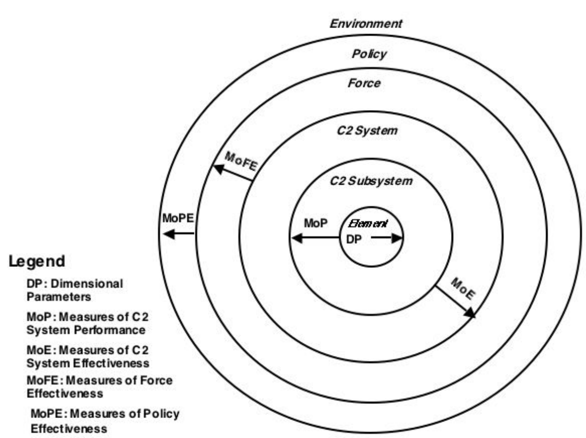

Figure 4. Relationships Among Classes of Measures of Merit

As can be seen in that figure, five levels of the hierarchy are envisioned:

- Measures of Policy Effectiveness (MoPE), which characterize the extent to which the sum of participants in an operations (e.g., military, other government agencies, coalition partners, International Organizations (IOs), Non-Governmental Organizations (NGOs), host nation institutions (e.g., police, judiciary)) are able to realize geo-political goals (e.g., transform a failed state into a successfully functioning state).
- Measures of Force Effectiveness (MoFE), which characterize how a force performs its military mission (e.g., loss exchange ratios; rate at which ground is taken);
- Measures of C2 Effectiveness (MoE), which characterize the impact of C4ISR systems within the operational context (e.g., ability to generate a complete, accurate, timely common operating picture of the battlespace);
- Measures of C2 System Performance (MoP), which characterize the performance of internal system structure, characteristics, and behavior (e.g., timeliness, completeness, or accuracy); and
- Dimensional Parameters (DP), which measure the properties or characteristics inherent in the C4ISR system itself (e.g., bandwidth).

In the extension of the NATO COBP to OOTW, it became apparent that it was necessary to extend the hierarchy of measures of merit to include MoPEs. This recognizes that the military plays only a contributing role in OOTW (i.e., it ensures that the environment is sufficiently safe and secure so that other organizations can function effectively).

As an illustration, Table 1 depicts representative measures of merit adapted from a recent case study of a hypothetical Civil-Military Operations Center (CMOC) (Reference 12).

Table 1. Strawman Measures of Merit (MoMs)

Measures of Policy Effectiveness	• Progress in transitioning from a failed to a stable state; e.g., – Successful democratization (e.g., ability to conduct a fair election) – Dealing with displaced persons (e.g., ability to relocate displaced families)
Measures of Force Effectiveness	• Ability of military to create and sustain a secure environment
Measures of C2 Effectiveness	• Quality of 1. Situational awareness 2. Synchronization of effort
Measures of C2 Performance	• Ability to perform CMOC tasks, functions, (e.g., time to complete a task)
Dimensional Parameters	• Communications (e.g., bandwidth, connectivity) • ADP support to personnel (e.g., quality, flexibility) • Collaboration tools (e.g., scalability, latency, security)

Historically, assessments of C4ISR systems have found it relatively straight forward to go “top down” to assess the implications of measures of merit at the top of the hierarchy on measures at the bottom of the hierarchy. For example, in the case of a theater ballistic missile defense problem, the goal of minimizing leakage of adversary missiles can readily be related to the required early warning time and maximum allowable C4ISR system induced delays (Reference 5). However, it is often more challenging to go "bottom up" to estimate credibly the effectiveness of weapons – C4ISR systems mixes in the context of the operational scenario.

• ***Scenarios.*** The NATO COBP concludes that it is necessary to perform assessments on the effectiveness of C4ISR systems in the context of appropriate scenarios.

Table 2 identifies a scenario framework that was formulated in the NATO COBP. The framework subsumes three major categories: external factors (e.g., political/military/cultural situation), capabilities of actors (e.g., friendly forces, adversary forces, and non-combatants), and environment (e.g., geography, terrain, man-made structures). The challenge is to explore the scenario space rapidly and to focus the assessment on the "interesting" regions of scenario space. The COBP cautions that, due to the complexity of the C4ISR system arena, limiting attention to a single scenario is almost always an error. Reference 13 illustrates a process for decomposing the three major categories of the scenario framework and suggests a mechanism for selecting a baseline scenario and interesting excursions.

Table 2. The Scenario Framework

External Factors	Economic/Political/ Military/Social Historic Situation	Mission Constraints & Limitations, ROE		Military Scope Intensity,Joint/ Combined
	National Security Interests			
Capabilities of Actors	• Organisation, Order of Battle, C2, Doctrine, Resources, Lessons Learned • Weapons, Logistics, Skills, Morale			
	Friendly Forces	Adversary Forces	Neutrals	Non-Combatants
Environment	• Geography, Region, Terrain,Climate, Weather • Civil Infrastructure (e.g., Transportation, Telecommunications, Energy)			

• ***Human Factors and Organizational Issues.*** A major challenge arises from the fact that C4ISR systems generally support distributed teams of humans operating under stress. This implies that the assessment must address both human factors and organizational factors. The NATO COBP introduces the following taxonomy for those two classes of factors. Human factors can be subdivided into human behavior (e.g., psycho-physiological; social cultural), decision making behavior (e.g., cognitive), and command style. Organizational factors can be decomposed into structural (e.g., span of control), functional (e.g., distribution of responsibility/authority), and capacity (e.g., a function of personnel, experience, training). Currently, our state of knowledge for both of those classes of factors is still primitive. However, in the near term, MORS is planning to conduct a workshop to explore how cognitive and behavioral factors influence C2 (Reference 14).

• ***Data.*** At a MORS Workshop on Simulation Technology **(**Reference 15), Walt LaBerge, then PDUSD(R&E), gave a presentation entitled "Without Data We Are Nothing". That observation is still relevant and the C4ISR system assessment community finds itself in the position of being "data poor". Although there have been repeated recommendations to establish a community-wide program to generate, collect, convert, manage, and verify, validate, and certify needed data, there has been little substantive action. The problem has become more challenging for OOTW where essential elements of information are often controlled by others (e.g., NGOs). Recently, MORS conducted a workshop ("Improving Defense Analysis Through Better Data Practices") that clarified the state of the practice in this area and formulated a set of recommendations to mitigate residual shortfalls (e.g., the need to generate metadata and make it widely available). These recommendations are summarized briefly in the next section of this paper. Administratively, the NATO COBP concludes that there is a need for a data dictionary/glossary at the outset of an assessment and a strategy for enhanced data management.

• ***Tools and Their Application.*** The NATO COBP concluded that no single assessment technique is likely to be sufficient for many of the information issues of interest. This suggests the need to formulate and implement a strategy that selects and orchestrates a mix of techniques consistent with the nature of the issues and key constraints (e.g., resources, lead time). Due to the increased interest in concepts like "information superiority" and "decision dominance", it is particularly important to have tools that represent adequately both friendly and adversary information processes. In addition, it is necessary to be disciplined in applying these tools. This suggests the desirability of employing formal experimental design matrices to govern the application of the tools and to support the generation of appropriate response surfaces (Reference 16). Frequently, it is advantageous to identify "interesting" segments of solution space, with respect to the issues at hand, by using very fast running tools as a pre-filtering mechanism. Once those "interesting" segments of solution space are identified, it is often appropriate to do more focused, in-depth assessments using more fine-grained tools (e.g., virtual models & simulations).

Of course, it is always highly desirable to use tools that have formally undergone verification, validation, and accreditation (VV&A). However, it is recognized that there are relatively few tools that have undergone such stringent quality control processes. To a limited extent, one can gain some confidence in the results if it can be demonstrated that independent assessments, drawing on the mix of techniques, can give rise to self-consistent findings.

To illustrate the current state of the art in C4ISR assessment tools, consider the following examples. To provide an initial "cut" at a complex problem, analysts are beginning to develop and employ system dynamics models. These object oriented models evolve from influence diagrams that characterize model variables, inputs, outputs, parameters, and influencing factors. A recent example of such a tool is the C4ISR Analytic Performance Evaluation (CAPE) family of models (Reference 17). These models capture C4ISR system performance by explicitly representing sensors of interest, aggregate aspects of C3 (e.g., explicit constraints on communications capacity; time delays experienced by command and control nodes), and the phases of the intelligence cycle. This tool was employed in OSD's C4ISR Mission Assessment to characterize the C4ISR systems required to support the engagement of time critical targets.

Agent based modeling represents a second promising technique for rapidly exploring solution space. This technique adopts a bottom-up, synthesist approach to the modeling of operations. It instantiates individual behaviors in the entities (e.g., response to other live or injured friendly or adversary entities; reaction to friendly or adversary objectives) and derives emergent behavior from the resulting interactions. As an example, a recently developed agent based model, Mana, has been developed by the Defence Operational Support Establishment, New Zealand, to help prepare its forces to participate in peacekeeping operations in East Timor (Reference 18).

Once the interesting parts of scenario space have been identified, it is useful to employ more detailed simulations to explore those regions in greater depth. For example, to support the assessment of the time critical target problem, DMSO has developed Pegasus, a federate of three constructive simulations: the Extended Air Defense Simulation (EADSIM), Eagle, and the Navy Simulation System.

In addition, federates are being developed that rely on virtual simulations to capture the response of the operators to a variety of stimulii. One such example is the Joint Virtual Battlespace (JVB) which the Army is developing to support the acquisition of the Future Combat System (FCS).

The NATO COBP establishes a standard for the soundness of the tools and their application to the problem at hand. It observes that a sound C4ISR system assessment must be characterized by Repeatability, Independence, Grounding in reality, Objectivity of process, and Robustness of results (RIGOR). Thus, analysts should be held to RIGORous standards, although not in the sense that the physical sciences espouse.

• ***Risk and Uncertainty Assessment.*** The NATO COBP notes that sensitivity analysis and risk assessment in C2 analyses have often been less than thorough because of the complexity of the issues being examined and limitations in time and resources. This is generally a mistake. The need for, and results of, sensitivity analyses should be stressed in discussions with the decisionmaker. As a minimum, the analyst should explore the robustness of the results to small excursions in the selected regions of scenario space. Ultimately, the role of the analyst is to illuminate uncertainty, not to suppress it.

In addition, there is increased interest on the part of the decision maker to receive a risk-based (vice a cost-benefit) assessment. For example, the legislation mandating the 2001 Quadrennial Defense Review specifically cast several of the questions in risk-based terms (Reference 19). The analysis community should draw upon the experience that other disciplines have amassed in performing such risk-based assessments (e.g., the insurance community, hedge funds).

• ***Iterative Approach.*** The nature of information problems is such that it is highly unlikely that meaningful results can be derived in a single pass through the assessment process. Thus, it is strongly recommended that an iterative approach be taken. The initial cut should be broad and shallow to identify the issues of interest and the relevant segments of scenario space. Subsequent iterations would be progressively narrower and deeper (drawing on suitable tools) to gain progressively more insight into the major questions of interest. Throughout this process it is critical that a peer review process be implemented in order to provide adequate quality control.

D. The Future

By using the basic re-engineering framework employed to assess the past (see Figure 1), it is feasible to highlight key recent major advances in C4ISR assessment and to identify major challenges that must be addressed (Figure 5).

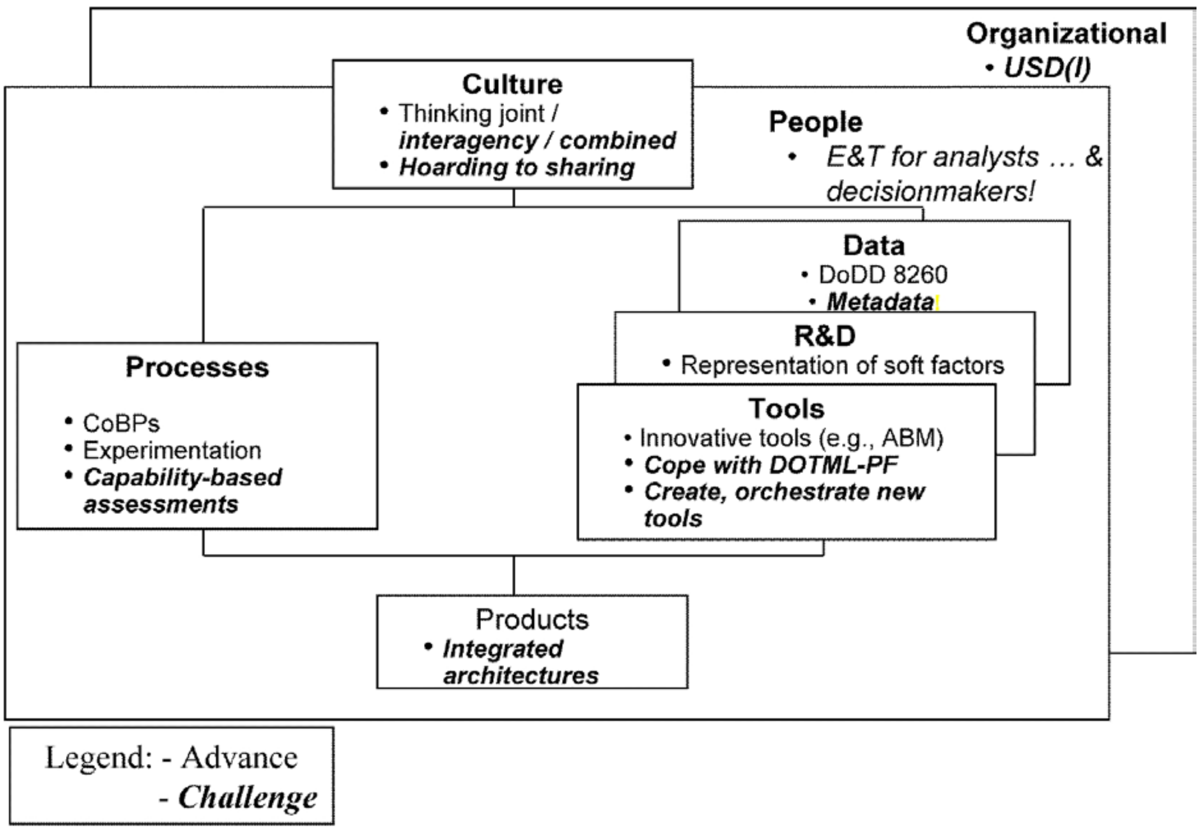

Figure 5. Looking Ahead: Recent Advances and Future C2 Assessment Challenges

• ***Advances.*** In looking back over the past thirty years, it is clear that we have made substantial progress in our ability to assess C4ISR systems. These advances are particularly apparent in five interrelated areas. First, and foremost, is the change in culture. Decisionmakers are keenly aware of the fact that meaningful assessments in national security require explicit consideration of C4ISR systems. That awareness is apparent in recent products from the Chairman, Joint Chiefs of Staff (CJCS) (References 20, 21) where first "information superiority" and then "decision superiority" were placed at the foundation of DoD's strategic vision. Sometimes that recognition is obscured in poorly worded questions (e.g., "How much is a pound of C4ISR systems worth?"), but it is no longer acceptable to unknowingly assume that "C4ISR systems are perfect". In addition, in a recent interview, the CJCS stated that "Joint warfighting is the key to greater things on the battlefield … the thing that enables that is C4ISR." (Reference 22).

A second important advance revolves around the improvements in the processes for assessing C4ISR systems. These advances have been the result of many workshops (particularly those sponsored by MORS), individual studies (e.g., OSD's C4ISR Mission Assessment and Information Superiority Investment Strategy), and special panels. With respect to the latter, the efforts of recent NATO panels have served to synthesize these earlier efforts, promulgate codes of best practice, and to identify the challenges associated with assessing C4ISR systems in the context of New World Disorder missions.

Third, there has been a great deal of creativity in devising and applying new tools that are better suited to support the assessment of C4ISR systems. These advances have occurred in the areas of system dynamics models (e.g., CAPE), agent based modeling (e.g., Mana), constructive simulations (e.g., JWARS), federates of constructive simulations (e.g., Pegasus), and virtual simulations (e.g., Joint Virtual Battlespace). Equally important has been the realization that no single tool or type of tool is adequate to support the assessment of C4ISR systems. This has led to the creative orchestration of tools to exploit their strengths and to compensate for their individual weaknesses.

Fourth, there is growing awareness of the criticality of data. Recently, DoD issued a directive and instructions on "Data Collection, Development, and Management in Support of Strategic Analysis" (References 23, 24). These products emphasize the generation of "analytical baselines" to provide a "warm" intellectual base for strategic analyses. Those baselines will subsume a scenario, concept of operations, and integrated data.

Finally, there is a growing sensitivity to the importance of performing joint experiments to provide insights into the potential contribution of C4ISR systems to operational effectiveness. These activities are focusing on the challenges of co-evolution wherein new C4ISR systems are a stimulus to new doctrine, concepts of operation, leadership, and training. In addition, these activities are the basis for acquiring the data and developing the models that the assessment community requires in order to perform credible assessments.

• ***Residual Challenges.*** However, in several key dimensions, the C4ISR assessment problem is getting harder. These residual challenges include the following:

Culture. As noted above, the culture of the military has begun to change to address joint (vice Service-specific) C2. However, that is only the first step on a longer journey. Given the evolving nature of the problem, where national security problems increasingly involve other government agencies (e.g., Department of Homeland Security, Department of State) and coalition partners, it is vital that the C4ISR assessment enterprise be expanded to address the role of these other participants. In addition, in order to transform the community's culture from one of hoarding to one of sharing (particularly for data), steps must be taken to dispel the fears that permeate the community (e.g., fears of misuse, misunderstanding, and adverse consequences).

Organizational. The recent decision to create a USD(Intelligence), fragments that element of the community from the broader C4ISR community. It remains to be seen what institutional steps can be taken to ensure that C4ISR assessments treat all elements of the community in a balanced way in future efforts.

People. The education and training of all of the people involved in the C4ISR assessment process is perceived to be a critical enabler of improved assessment. This subsumes courses to ensure that analysts are well versed in the latest methodologies and tools, as well as the challenges associated with dealing with massive amounts of heterogeneous data. But it must be stressed that education needs to go both ways – decision makers will require education as well as the analyst. The recently issued "Decisionmaker's Guide to the NATO CoBP for C2 Assessment" (Reference 25) reflects the kind of material that is needed to support that function. In particular, there is great value in providing the decision maker with lists of questions that he should pose to the analyst as the assessment proceeds.

Processes. Throughout the Cold War, the C4ISR assessment community was directed to perform threat-based assessments (e.g., focus on selected scenarios documented in SCORES). The future challenge will be to perform capability based assessments that seek to identify break points in operational effectiveness across a broad spectrum of feasible adversaries. In order to perform these assessments effectively, it will be necessary to perform broad, exploratory analyses (employing fast running, high level assessment tools) to identify "interesting" segments of scenario space. Those "interesting" segments should then be assessed in greater depth using an appropriate set of tools. These assessments will be particularly challenging for mission areas that are of increasing importance in a transformed force (e.g., Information Operations, Stability and Support Operations, counter-terrorism).

Tools. It is widely recognized that the goals of transformation will not be achieved solely through materiel solutions. As stated in Joint Vision 2020 (Reference 21), it will require co-evolution across all the dimensions of DOTML-PF. Unfortunately, the assessment community currently has virtually no tools that enable us to vary all of those dimensions flexibly (e.g., most tools "hard wire" most of those dimensions). Thus, a new tool chest will be needed, whose components can be orchestrated effectively, to redress this critical shortfall.

R&D. Among the critical elements influencing C2 are cognitive and behavioral factors. Our existing tools tend to revert to the 1970's solution to this issue: they ignore these factors or regard them as second or third order effects. In a world where coercive operations are becoming the norm, these assumptions are unacceptable. There are preliminary efforts to address this issue (e.g., NATO SAS-050) but fundamental research is required to establish a theoretical base from which we can iteratively develop new tools and guide the collection of meaningful data.

Data. It is being increasingly recognized that timely, available, understandable data constitutes the "Achilles heel" of the C4ISR assessment problem. Although the new DoD Directive on data is an important beginning, the data problem itself entails the need for changes in culture, education and training, and community processes (e.g., the need for rich, disciplined metadata) (Reference 26).

Products. In the latest version of the DoD Directive governing the acquisition of DoD systems, DoD 5000 (Reference 27), it places extensive emphasis on the generation of a family of integrated architectures (subsuming operational, system, and technical perspectives). However, the community currently lacks an understanding of how to create and assess these architectures efficiently. Promising preliminary assessment efforts have focused on creating federates of tools that link combat models, communications models, and process models (e.g., Bonapart) to generate executable models (e.g., colored Petri Nets) of proposed architectures. However, these efforts are in their infancy, and an enormous amount of effort is required to develop methods and tools that are credible, scalable, and efficient to employ.

• ***Summary.*** The C4ISR system issues confronting the DoD inherently involve complex, poorly defined problems. Consequently, the C4ISR system assessment process can not be reduced to a "cook book" or implemented through linear thinking.

If future C4ISR assessments are to be responsive to decisionmakers' needs, it will require two major initiatives. First, efforts must be undertaken to enhance cross-community communications. This must be done across key organizations (e.g., OSD, Services, defense agencies, inter-agency, coalition) and across the participants in the assessment process (e.g., decisionmakers, technologists, operational users, analysts). Second, the community must systematically address *all* of the residual challenges cited above, particularly in the areas of culture, education and training (of the analyst and the decisionmaker), data, and product creation.

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