

C4ISR Issues Associated with the Shinseki Vision: An Application of the NATO Code of Best Practice for C2 Assessment

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Abstract

In the summer of 1999, the new Chief of Staff of the Army, General Eric Shinseki, articulated a new vision for the US Army. He observed that for early entry in smaller scale contingencies, the major fighting forces of the US Army were either too “heavy” to deploy rapidly (i.e., using the 70 ton Abrams tank as the primary weapon system) or too “light” to be effective once they arrived (i.e., lacking substantial mechanized capability). To remedy this situation, he proposed the creation of “medium weight” brigades that would be built around a proposed family of Future Combat Vehicles. These 20 ton vehicles (probably wheeled vice tracked) would be designed to be transportable by C-130 aircraft. One of the initial goals of such a brigade would be to support early entry operations in a future theater of conflict within 96 hours.

To understand the C4ISR ramifications of such a medium weight brigade, a multidisciplinary team of analysts was assembled to perform an initial conceptual study of the Shinseki Vision. The team used the NATO Code of Best Practice for C2 Assessment to guide their deliberations. To that end, the team characterized the new organizational features of the proposed medium weight brigade; identified a set of scenario conditions as context for the assessment; and formulated a relevant set of measures of merit. The primary findings serve to identify key issues, which should be the subject of more in-depth assessments.

1. Goal and Objectives

The goal of this paper is to identify and explore potential C4ISR issues associated with General Shinseki’s vision for a transformed Army by applying the NATO Code of Best Practice (COBP) for C2 Assessment [RTO Technical Report 9, 1999]. Consistent with this goal, two objectives are sought. First, the paper will employ this process to identify key C4ISR issues that are worthy of future, more in-depth assessments. Second, it will explore the utility of applying the NATO COBP to a complex, ill-defined C2 problem area.

To achieve those objectives and goal the paper will briefly summarize the major recommendations of the NATO COBP. Those recommendations will then be applied to one phase of the Army transformation process. The paper will conclude by summarizing the lessons learned in applying the NATO COBP.

2. Approach

Figure 1 provides an overview of the major elements of an effective C2 assessment that are identified in the NATO COBP. The figure highlights the major steps that should be performed in the assessment process. Note that the NATO COBP actually recommends that extensive feedback mechanisms be implemented among the major steps in the process. The following discussion is broadly keyed to the first six steps in this framework.

The NATO COBP states that the scope of such an undertaking generally requires an interdisciplinary team. This includes individuals skilled in operations research, modeling and simulation (M&S), and C2 operations, systems, and technology. The participants in this preliminary study spanned this set of skills and experience (see Acknowledgments).

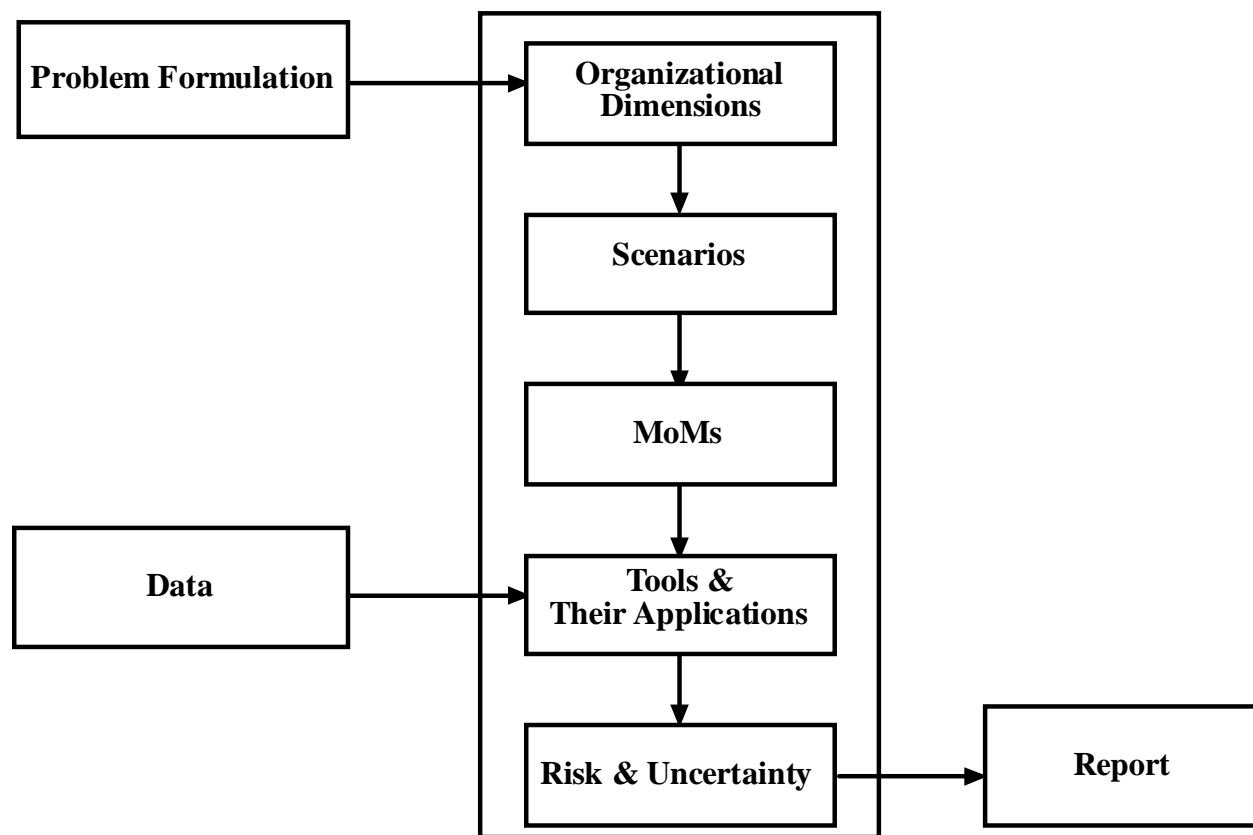


Figure 1. Recommended C2 Assessment Methodology

3. Problem Formulation

The NATO COBP observes that extreme care must be taken in structuring and decomposing the problem. In most C2 assessment, it is extremely 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.

To support the formulation of the problem, it is important to address the following questions: what, why, who, where, when, and how.

3.1 What

In the Shinseki vision of new medium weight brigades, three distinct phases are identified (see Figure 2). In the near term, two Initial Brigade Combat Teams will be created drawing on current, off-the-shelf technology. Subsequently (in the 2005 time period), Interim Brigade Combat Teams will be created employing evolutionary technology. Eventually (in the 2012 time period), Objective Brigade Combat Teams will be developed, based on revolutionary technology. For the purposes of this paper attention will be restricted to the C4ISR issues associated with the Interim Brigade Combat Teams in the 2005 time period. Consistent with GEN Shinseki's vision, emphasis will be given to the needs of those forces in the context of early entry operations in smaller scale contingencies.

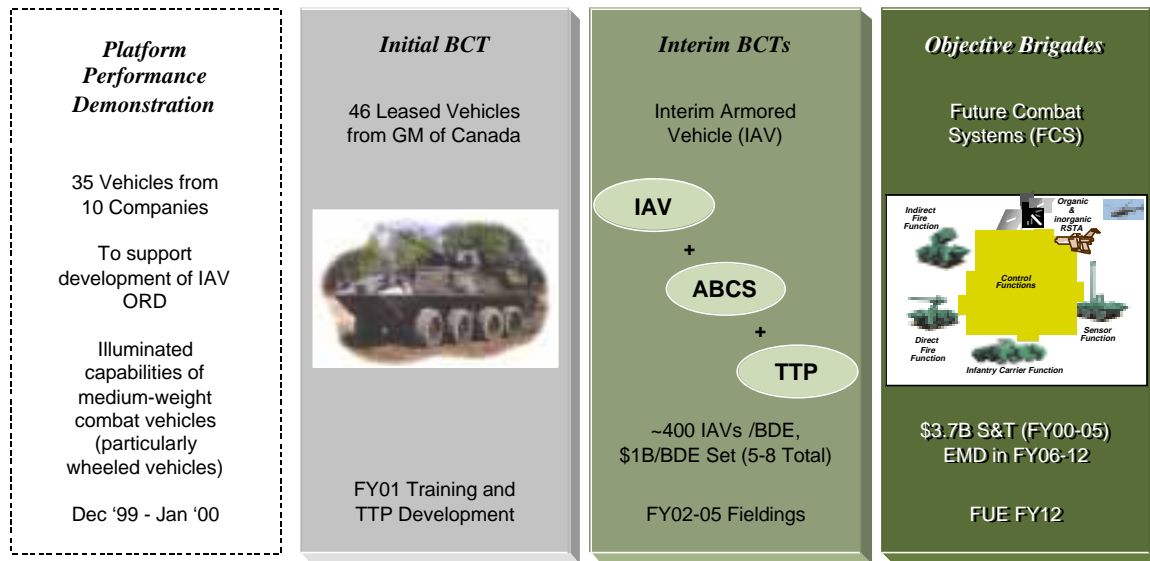


Figure 2. Time Phasing of the Brigade Combat Teams

3.2 Why

There are many reasons why the identification of the C4ISR issues associated with the Interim Brigade Combat Team is important to pursue. Foremost among them is the realization that this activity is still in the early conceptual stage [TRADOC, 2000]. Thus, this paper identifies and explores the C4ISR issues associated with the Interim Brigade Combat Team as one step in the further refinement of the concept. Subsequently, these issues must be assessed further as the refined concept is subject to advanced experimentation, the development of a system of systems investment strategy, and ultimately the acquisition of a viable system and operational capability.

3.3 Who

The primary audience of this activity is senior decision makers on the US Army staff (e.g., the Chief and Vice Chiefs of Staff; senior officials charged with refining and implementing the Interim Brigade Combat Team concept). Thus the intention of this paper is to identify those major issues that would be of interest to those decisionmakers.

Although the central focus of the assessment is on a US Army concept, it is recognized that the proposed Interim Brigade Combat Teams would almost certainly operate in a Joint Task Force, in the context of combined operations. Thus, special attention will be given to the identification of C4ISR issues associated with operating with other Services and coalition partners. In addition, General Shinseki's vision calls for these Interim Brigade Combat Teams to play substantive roles in Major Theater Wars (MTWs) as well as Operations Other Than War (OOTW). This implies that the concept must be flexible enough to function effectively with the heterogeneous participants that are typically involved in OOTWs (e.g., International Organizations, Non-Governmental Organizations, indigenous authorities/organizations).

3.4 Where

The primary purpose of the Interim Brigade Combat Team will be to support early entry in a smaller scale contingency operation. The C4ISR issues associated with those operations will be sensitive to many of the assumptions concerning the scenario in which those assets are employed. A baseline scenario will be derived below and variations identified that would be appropriate for the sensitivity phase of the assessment.

3.5 When

Consistent with General Shinseki's vision for the Interim Brigade Combat Team, the assessment will be set in the 2005 time period. It will be assumed that C4ISR systems and processes associated with the programs and plans of all of the Services for that time period will be available.

3.6 How

One of the major steps that must be performed in order to identify the key C4ISR issues of interest is to identify meaningful Measures of Merit (MoMs). A strawman hierarchy of MoMs is presented and discussed below. Subsequently, a strategy is needed to select and orchestrate a mix of assessment tools and techniques to evaluate these MoMs.

4. Organizational Dimensions

The NATO COBP observes that a primary challenge arises from the fact that C2 deals with distributed teams of humans operating under stress. In addition, changes to the C2 system will often lead to changes in tactics, techniques, and procedures (TTPs), doctrine, or related factors, which must be considered in the assessment.

4.1 Organizational Description

Based on the Shinseki Vision, a preliminary Organizational & Operational (O&O) Plan [TRADOC, 2000] has emerged for the Interim Brigade Combat Team and the associated Division/Corps Augmentation (see Figure 3). There are several key features of this organization that could have important C4ISR ramifications. They include: combined arms at the lowest organizational level; an expanded Reconnaissance, Surveillance, Target Acquisition (RSTA) Squadron for collection of information; a Military Intelligence Company to support analysis; a Signal Company vice a Signal Platoon; an Artillery Battalion at Brigade (vice the normal Division level); the absence of an organic air defense element (note: it will be at the Division/Corps Augmentation), and the extensive use of "reachback".

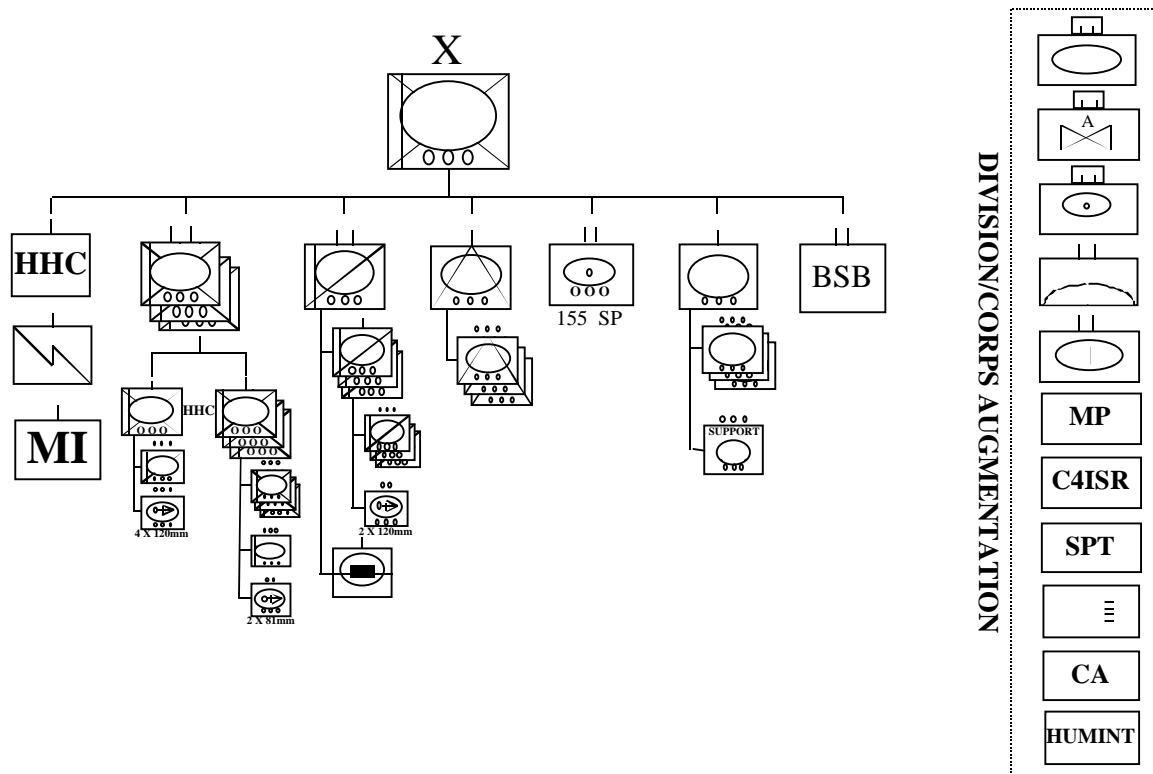


Figure 3. Proposed Organization for the Interim Brigade Combat Team

The heart of the proposed organization is the Infantry Battalion. It includes combined arms at the company level comprised of infantry, mobile support guns, mortars, anti-tank capabilities, and snipers. It will execute dismounted infantry assault supported by Fire Support Teams (FIST), fires from organic medium weight Infantry Carrier Vehicles, a mobile gun system, and mortars. It includes robust reserves for agility and versatility (i.e., four platoons of four squads per company) and is internetted for "point and shoot."

The RSTA Squadron is charged with developing the understanding of the tactical picture around and within the maneuver battalions' and brigade's area of responsibilities. It subsumes a Reconnaissance Troop that provides human intelligence (HUMINT) and technology based reconnaissance; a Surveillance Troop that employs three methods of surveillance (by stealth, by human

collection, and, if required, by fighting for information); and a variety of collection assets (e.g., unattended air vehicles, ground sensors).

4.2 Organizational Issues

A preliminary assessment of this proposed organization raises several intra-Army and inter-Service/organization issues.

Intra-Army Issues. The proposed organization raises a host of intra-Army interoperability issues. For example, it is not clear what is being done to ensure interoperability of the Interim Brigade Combat Team with several key organizational entities (e.g., the Initial Brigade Combat Team; the Digitized Division; the non-Digitized Division; Corps elements). Note that given the phased implementation of Army systems, several generations of systems could conceivably be required to interoperate during the same operation. In addition, it is not clear how the Interim Brigade Combat Team would implement "reachback" operations (e.g., would it employ a state-of-the-art collaborative tool such as the Information Workstation (IWS)?).

Inter-Service/Organizational Issues. Since the Interim Brigade Combat Team would inevitably participate in joint or combined operations, it poses the following inter-Service issues: How would the Interim Brigade Combat Team:

- interface with the USAF to coordinate close air support operations (e.g., where is the Tactical Air Combat Party)?
- coordinate with the USMC, if the latter were responsible for forced entry operations (e.g., would they exchange liaison officers)?
- link with the USN to receive indirect fire support (e.g., how would coordination be done to call for naval gun fire or support from Tomahawk Land Attack Missiles)?

Note that each of the other Services is in the process of transforming their theater/tactical forces (e.g., the USAF is creating Air Expeditionary Forces). It is unclear what steps are being taken to ensure that the C4ISR systems and processes associated with these Service transformations are mutually consistent.

Second, there are major initiatives underway to enhance shared awareness of the tactical air and ground situation (e.g., Single Integrated Air Picture, Single Integrated Ground Picture). It is unclear how the Interim Brigade Combat Team would participate in the creation and sharing of those products.

Finally, the Interim Brigade Combat Team would likely have to interoperate with military coalition partners and the broad spectrum of participants in OOTWs (e.g., international organizations, other US Agencies (e.g., Agency for International Development), non-governmental organizations). Although many of these linkages have historically been implemented through Civil Military Operations Centers (CMOCs), those potential linkages with the Interim Brigade Combat Teams remain to be defined.

5. Scenario Dimensions

The NATO COBP concludes that it is necessary to perform assessments of the effectiveness of C2 in the context of an appropriate scenario. Figure 4 identifies a scenario framework that was identified 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). The challenge is to explore the scenario space rapidly and to focus the assessment on the "interesting" regions of scenario space. The NATO COBP cautions that, due to the complexity of the C2 arena, limiting attention to a single scenario is almost always an error.

External Factors	Political/Military/Cultural Situation	Mission Objectives Mission Constraints & Limitations Rules of Engagement	Mission Military Scope } Tasks Intensity
	National Security Interests		
Capabilities of Actors	<ul style="list-style-type: none"> • Organization, Order of Battle, C2, Doctrine,... • Weapons, Resources,... • Logistics, Skills, Morale,... 		
	Friendly Forces	Adversary Forces	Non-Combatants
Environment	<ul style="list-style-type: none"> • Geography/Region/Terrain Features/Accessibility/Vegetation • Climate/Weather • (Civil) Infrastructure (e.g., Transportation, Telecommunications, Energy) 		

Figure 4. The NATO COBP Scenario Framework

To illustrate one means of developing a baseline scenario (and potential scenario excursions), consider the approach promulgated in [Starr, 1996]. In that approach factors associated with the NATO COBP Scenario Framework were enumerated specifically. For each of those factors, values were identified associated with "easier" and "more difficult" scenarios, from a C4ISR perspective. Using these bounding values as guides, a potentially interesting baseline scenario was developed by selecting specific values for each of these factors (see Tables 1 - 4). By selecting alternative values for one or more of those factors, one can readily define alternative scenarios as the basis for sensitivity analyses.

FACTORS	EASIER	MORE DIFFICULT	SELECTED
● Conflict			
- Level	Low end of spectrum	High end of spectrum	SSC (Peacemaking)
- Concurrency	None	At least one	None
● Geopolitical factors			
- Goals	Clear, unambiguous	Vague, ambiguous	Clear
- Cultural factors	Homogeneous	Heterogeneous	Heterogeneous
I Initial Conditions			
- Warning time	Extensive	Little/no	1 month
- State of Reserves	Mobilized/prepared	Unprepared	Mobilized/prepared
- Plans	Existing	None	Prelim existing
- Prior OPTEMPO	Moderate	Very high	Very high
- Phase of conflict	Late entry	Forced entry	Early entry
I Other participants			
- Presence of neutrals	None	Many	Some
- NGOs, PVOs	Not present	Extensive presence	Moderate
- Media	Benign	Hostile	Hostile

Table 1. Key Scenario Factors: Mission Context

FACTORS	EASIER	MORE DIFFICULT	SELECTED
● US Forces			
- Numbers	Few	Large Force	5-10 K
- Mix	Single Service	Joint	Joint
- Equipment Prepositioning	Extensive	None	Limited
- Weapons systems	"Dumb" weapons	Precision weapons	Precision
● Multinational			
- Numbers	Few	Large Forces	Few
- Mix	Homogeneous	Heterogeneous	Primarily homogeneous*
- Equipment	Sophisticated	Primitive (e.g., non-interoperable with NATO)	Sophisticated, but 1 generation behind IBCT
- Affiliations	Long term allies	No alliance relationship	Primarily long-term allies

* with some low end participants

Table 2. Key Scenario Factors: Friendly Forces

FACTORS	EASIER	MORE DIFFICULT	SELECTED
- Numbers	Few	Large numbers	1 Division
- Composition	Single Service	Joint forces	Primarily ground forces
- Equipment	Unsophisticated	Sophisticated	1-2 generations behind
- Tactics	Conventional	Counterinsurgency	Conventional
- Possession of special assets	None	<ul style="list-style-type: none"> • Weapons of Mass Destruction (WMD) • Ballistic/Cruise Missiles (CM) • ASATs 	<ul style="list-style-type: none"> • Chem • CMs (few) • No
- IW ability	None	Sophisticated	Some (jamming)
- C4ISR	Primitive	Sophisticated	<ul style="list-style-type: none"> • Commercial - Comms - Space imaging - Navigation
- SAMs	None	Sophisticated	Manpads, SA-6s
- Ability to impede entry	None	Extensive	Mine fields

Table 3. Key Scenario Factors: Adversary Forces

FACTOR	EASIER	MORE DIFFICULT	SELECTED
● Geography/Climate			
- Hemisphere	Northern	Southern	Northern
- Area of Theater	Small (e.g., Haiti)	Very Large (e.g., China)	Moderate
- Distance to AOR	Close (e.g., Haiti)	Far (e.g., Korea)	5-6 K nmi
- Terrain	Flat, smooth	Mountains	Rugged
- Foliage	Little or none	Triple canopy jungle	Deciduous
- Proximity to ocean	Littoral (e.g., Korea)	Inland (e.g., Central Russia)	Proximate
- Weather/sunlight	Moderate, clear	Adverse, few hours of daylight	Moderate-to-adverse
● Infrastructure			
- Transport (e.g., ports, airfields, roads)	Extensive (e.g., Europe)	Very limited (e.g., Central Africa)	Moderate
- PTT	Extensive (e.g., Europe)	Very limited (e.g., China)	Some cellular
- Urban areas	Few	Many, built-up	Some

Table 4. Key Scenario Factors: Operational Environment

6. Measure of Merit (MoMs) Dimensions

The NATO COBP states that no single measure exists that satisfactorily allows the assessment of either the overall effectiveness of C2 or the performance of C2 systems.

A hierarchy of MoMs is envisioned that subsumes:

- Measures of Policy Effectiveness, which characterize the extent to which the participants in an operation are able to achieve national (or international) security objectives (e.g., help a failed state provide basic societal functions);
- Measures of Force Effectiveness, which characterize the effectiveness of the military component of the force (e.g., time required to halt the attack);
- Measures of Mission Effectiveness, which characterize the ability of the military force to perform key subordinate missions (e.g., the ability to perform the four major missions identified in Joint Vision 2010 -- precision engagement, dominant maneuver, full spectrum protection, focused logistics);
- Measures of Functional Performance, which characterize the ability of the C4ISR-weapons system mix to perform the critical functions associated with the key mission areas (e.g., ranging from the target engagement process through key "ilities" such as interoperability);
- Dimensional Parameters, which measure the properties or characteristics inherent in the C4ISR-weapons systems (e.g., for communications, associated bandwidth and jam resistance).

As an illustration, Table 5 enumerates selected MoMs that are germane to an assessment of key Interim Brigade Combat Team issues. The challenge is to enumerate a more complete set of MoMs, evaluate those measures, and capture and determine the linkages among these measures.

Measure		Representative Examples
Policy Effectiveness		<ul style="list-style-type: none"> • Restore <i>status quo ante</i>
Force Effectiveness		<ul style="list-style-type: none"> • Time to halt the attack • Friendly, neutral casualties • Collateral damage
Mission Effectiveness	Precision Engagement	<ul style="list-style-type: none"> • Ability to engage massed armor at ranges beyond line of sight
	Dominant Maneuver	<ul style="list-style-type: none"> • Ability to understand disposition, intent of Blue and Red, consistent with mission needs (while denying same to Red)
	Full Spectrum Protection	<ul style="list-style-type: none"> • Ability to engage Red platforms, in a countermeasures environment, at tactically useful ranges
	Focused Logistics	<ul style="list-style-type: none"> • Ability to resupply IBCT with expendables (e.g., POL, ordnance), just in time
Functional Performance	"ilities"	<ul style="list-style-type: none"> • Intra-Army and inter-Service/organization interoperability • Transportability of key C4ISR weapons systems • Survivability (as viewed from a system-of-system vice platform perspective)
	Target engagement functions	<ul style="list-style-type: none"> • E.g., P_d vs P_{FA}; IFFN performance; ability to classify
Dimensional Parameters	C4ISR	<ul style="list-style-type: none"> • Communications bandwidth; jam resistance
	Fighting vehicle	<ul style="list-style-type: none"> • E.g., weight, caliber of weapon

Table 5. Selected MoMs for the Interim Brigade Combat Team

7. Tools and Their Application

Table 6 depicts a spectrum of assessment techniques. The NATO COBP concluded that no single assessment technique is likely to be sufficient for many of the C2 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 “information 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. Frequently, it is advantageous to identify “interesting” segments of solution space, with respect to the issues at hand, by using very fast running tools (e.g., systems dynamics models) as a prefiltering 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).

Technique	Typical Application	Systems	People	Ops/ Mission	Resources	Lead Time		Credibility
						Create	Use	
Analysis	Closed Form; Statistical	Analytical	Assumed or Simulated	Simulated	Relatively Modest	Weeks to Months	Weeks to Months	Fair to Moderate
Constructive	Force on Force Models; Communication Systems	Simulated	Assumed or Simulated	Simulated	Moderate	Months to Years	Weeks to Months	Moderate
Virtual	Human in the Loop	Simulated	Real	Simulated	High	Years	Months	Moderate to High
Live	CPX* FTX*	Real	Real	Real or Simulated	Very High	Years	Weeks to Months	High
Actual Ops	After Action Reports; Lessons Leamed	Real	Real	Real	Extremely High	N/A	N/A	Very High

*CPX - Command Post Exercise
*FTX - Field Training Exercise

Table 6. Spectrum of Candidate Assessment Techniques

As a preliminary activity, the Mission Oriented Approach to C4ISR analysis [Signori and Starr, 1987] has been applied to selected mission areas of interest to the Interim Brigade Combat Team. In this approach a top down decomposition of the mission is performed to assess what is to be done (operationally), how it is to be performed (operationally), and what is required (from a systems perspective). For the mission area of precision engagement, this assessment serves to

identify many of the key C4ISR performance and systems issues that must be addressed by the Interim Brigade Combat Team. In particular, there is concern about the ability of the 20 ton medium weight vehicle's ability to be effective and survivable in an operation when the adversary has heavier armored vehicles. To deal with that situation in the baseline scenario cited above, it requires a system of systems approach featuring extensive use of indirect fire assets and C4ISR at ranges that enhance the survivability of the Interim Brigade Combat Team's assets. Consistent with that operational concept, it implies the following C4ISR functional needs:

- the ability to detect and locate adversary targets with suitable range, reliability, accuracy, and timeliness;
- the ability to discriminate foes from neutrals reliably in a timely way; and
- the ability to classify detected targets (e.g., discriminate tractors from tanks) reliably (perhaps through the timely, accurate, and unambiguous fusion of sensor information from complementary systems).

In subsequent work, variants on existing systems dynamics models [Richards et al., 1997] will be employed to develop preliminary estimates of the functional needs that must be satisfied if the Interim Brigade Combat Team is to be effective and survivable.

8. Sensitivity Analyses

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 decision maker.

For the case of the Interim Brigade Combat Team, one of the major sources of uncertainty arises from the broad set of scenario conditions in which the capability may be employed. As an illustration, future assessments should consider at least the following variants in scenario space:

8.1 *Mission Context.*

- **Concurrency.** The baseline scenario assumed that the operation would not be concurrent with any other operation. It would be important to assess the impact of a concurrent operation, particularly with respect to the competing demands on lift and sustainment assets.
- **Presence of Neutrals.** The baseline scenario assumed that the operation would feature some neutrals. If the numbers of neutrals in the battlespace dominated the population (as it did in Kosovo), it would put a much higher premium on the ability to discriminate reliably foes from neutrals.

8.2 *Friendly Forces*

- **Equipment Prepositioning.** The baseline scenario assumed that limited prepositioning of equipment had been performed. If there were no prepositioning of equipment, it would greatly stress the C3I to support focused logistics in the initial stages of the operation.

- **Multinational Mix.** The baseline scenario assumed that the force would be primarily homogeneous with some low end participants. If the force were highly heterogeneous, it would pose severe interoperability problems. In the past, there has been a tendency to use liaison teams (with appropriate cultural skills and mixes of C4ISR equipment) to compensate for these interoperability shortfalls.

8.3 *Adversary Forces*

- **Possession of Special Assets.** The baseline scenario assumed that the adversary did not possess a ballistic missile capability. If he did possess such a capability, the impact could be profound. This would include, *inter alia*, the need to minimize the Blue force's footprint in the theater, and the requirement for a timely, reliable missile alerting capability.
- **Information Warfare (IW) Ability.** The baseline scenario assumed that the adversary would have only limited IW capability (e.g., limited jamming assets). An adversary with more sophisticated IW capability (e.g., the ability to exploit vulnerabilities of key software operating systems or the ability to degrade the capability of GPS) would place substantial demands on the robustness of a broad set of C4ISR systems.

8.4 *Operational Environment*

- **Proximity to Ocean.** The baseline scenario assumed that the area of operations would be proximate to the ocean, facilitating use of naval lift. If that assumption did not hold, it would significantly complicate the transport of heavy or oversized systems to the theater. This would put a premium on C4ISR systems that were relatively light and small.
- **Urban Areas.** The baseline scenario assumed that the theater of operations would be characterized by some urban areas. If the theater featured many, built up urban areas, it would substantially alter the nature of the operation and the required C4ISR assets (e.g., GPS tends to be of limited utility in urban canyons).

These examples suggest that relatively small changes in the scenario assumptions can have a major impact on the associated C4ISR needs. Consequently, it is vital that sensitivity analyses be conducted in a disciplined fashion to assess these scenario variants (in various combinations), systematically.

9. Summary

Under the leadership of the Chief of Staff, the Army is in the midst of a transformation of the force. It is becoming clear that this proposed transformation will have a profound impact on the Army's C4ISR process and system. This paper has attempted to apply the NATO COBP as a means of identifying the issues that the Army must address to ensure that the evolving C4ISR capability is commensurate with their needs. It is concluded that the NATO COBP can serve as a useful organizing concept for structuring and addressing a complex, potentially ill-posed C4ISR problem. Consistent with the guidance in the NATO COBP, it is clear that the approach must be performed iteratively. An initial broad, shallow iteration serves only to provide broad structuring

and a preliminary identification of potentially important issues. Progressively narrower, deeper cuts must be performed to validate those issues and to perform the needed assessments and sensitivity variants.

10. Acknowledgements

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