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Abstract

Terrain and weather effects represent a fundamental, enabling piece of battlefield information supporting situation awareness and the decision-making processes within the domain of Command and Control (C2). These effects can both enhance or constrain force tactics and behaviors, platform performance (ground and air), system performance (e.g. sensors) and the soldier.

Battlefield Management Language (BML) is being developed as a common representation of military mission suitable for automated processing. Within NATO the task group MSG-048 "Coalition BML" is defining a BML using the Command and Control Information Exchange Data Model (C2IEDM) as a lexicon. The integration of actionable terrain and weather information within a Coalition C2 process can best be accomplished by developing a common "abstract" representation of geo-environmental objects – a geoBML. These common spatial objects are defined as those required in a specific mission context (e.g., an "engagement area"). Also required is the explicit set of tactical relationships between the expanded set of geo-environmental objects and military missions. geoBML has three critical components: 1) a formal language and grammar tightly coupled to doctrine, 2) an enabling context of use, and 3) an explicit computational representation enabling presentation to military decision makers and input to intelligent C2 applications.

1 Introduction

Coalition Interoperability has typically been addressed though message exchanges between Command and Control (C2) systems. The process of creating actionable geo-information for plans and support operations is not typically considered as critical to interoperability. However, as forces move toward Net-Centric Operations, and basic interoperability is improved, more emphasis will be put on the planning process. Along with these increased capabilities will be a need for greater utilization of terrain and weather decision aids. These decision aids should be shared among coalition partners for maximum effectiveness.

In this paper, we present a framework for actionable geo-information within a Command and Control context. The concept of a Battle Management Language is extended to address geospatial concepts and the computation required to create this information.

1.1 Effective Information Exchange in a Network-Centric Environment

In a network-centric environment, information empowers the participants (both human and automated decision systems). The exchange of information has to run smoothly such that fleeting opportunities can be noticed and exploited by the participants in time. In order to optimize the information exchange and to deal in a timely fashion with the huge amount of information exchanged, forces have to be equipped with smart C2 systems which automatically pre-process the incoming information. It is not only necessary that the right information is available at the right time, it is also necessary that the information is understood correctly at the right time (cf. [1], chapter 12). To achieve these goals is difficult, and it is even more difficult if the forces in question are coalition forces. Coalition forces often rely on nation-specific C2-systems developed with nation-specific doctrines in mind. Therefore, even if information is exchanged in time on the information level, the "understanding" of the exchanged information by the C2-systems normally will be different and thus a force that receives information often reacts to it a different way than the sender had intended.

The effective empowerment of Coalition C2 is predicated on the satisfaction of two key conditions. First, as Alberts and Hayes [1, chapter 7] described, the most direct way to ensure a desired degree of interoperability is to exchange information by communicating in a common language. With respect to forces, this idea has guided the development of a specific (military) variety of English and the standardization of military messages, e.g., the standard form of an Operations Order is determined by STANAG 2014. Military doctrines have leveraged these standards, such that for example professional NATO soldiers know by heart how an Operations Order has to be structured and how such an order is to be read and interpreted. However, many military messages formulated according to military doctrine are "free texts" and as such hard to process automatically. Second, as Devlin presents [2, pp. 57-75], the effectiveness of any interaction is dependent on degree and quality of a shared context among the participants. This is an especially significant condition for geo-environmental information. Knowledge of terrain and weather is, in and of itself, a context applied in a multitude of military decisions regarding tactics and tasks. Consequently, the tight coupling of geo-environmental information with doctrine, missions and defines geoBML.

1.2 Relating Effects to Missions

There are currently well-defined planning processes for military operations, such as the Military Decision Making Process. There is also doctrine on how the environment affects both coalition and enemy operations. The end result is identifying how the battlefield/battlespace environment influences the operation and courses of action of the threat and friendly forces. The US Army uses OAKOC - Observation and fields of fire, Avenue of approach, Key terrain, Obstacles, Concealment and cover.

C2 systems are evolving. The future systems must not only be interoperable but must also incorporate automated decision aids, such as course of action development and analysis tools, mission rehearsal simulations and terrain analysis tools. Current C2 systems use a variety of digital map data for display, but this map information is not well integrated with C2 data and information. In particular, advanced terrain reasoning will not be supported in future systems without a better integration of actionable geo-information.

There are many interoperability issues associated with the lack of clear semantics for military missions. One approach to improving interoperability is to have all systems use the same representation for their data and information. However, this has not worked in practice. Rather, interface services and layers have been devised to share data and information that needs to be exchanged. Mission planning is dependent upon terrain. However, terrain data is not often shared between different systems. But to have consistent analysis between systems, the critical effects of terrain should be represented in such a way that they can be exchanged as well.

An example is the determination of boundaries between two coalition forces. Terrain is a key factor in this determination, but if the missions of the different forces are known, then terrain analysis can be conducted to yield specific terrain products. Since the determination of a boundary must consider both forces, and their missions, there should be a standard representation of these missions and also the effects of terrain upon these missions. However, the specific terrain data used need not be shared.

1.3 Actionable geo-Information in a Standard C2 Lexicon

Development of an unambiguous C2 Language requires a vocabulary by which the terms are fixed in their meaning. The Multinational Interoperability Programme has already produced a semantic definition for C2 terms suitable for coalition operations. This is documented in the Command and Control Information Exchange Data Model (C2IEDM). It will be accepted as a NATO standard in the next version – the Joint Command, Control and Consultation Data Exchange Model (JC3IEDM).

The C2IEDM consists of both a Data Model and an Exchange Mechanism. The Data Model is intended to represent the core data types identified for exchange across multiple functional areas. It lays down a common approach to describing the information to be exchanged in the command and control domain. Thus, the approach is generic and not limited to a special level of command, force category, etc. In general, C2IEDM describes all objects of interest on the battlefield, e.g., organizations, persons, equipment, facilities, geographic features, weather phenomena, and military control measures such as boundaries using a common and extensible data modeling approach.

In summary, the Data Model of the C2IEDM defines the semantics of coalition C2 terms, for a well-established and standardized vocabulary of a C2 Language. In addition to the Data Model, there is an Exchange Mechanism that uses a replication protocol that allows the exchange of data between two systems that have a C2IEDM Data Model.

Independent of country or doctrine employed, military commanders regularly utilize information, knowledge and understanding of terrain, atmosphere and weather impacts on military operations. Geo-environmental information provides a base context for military decision making. Additionally, geo-environmental information has a ubiquitous quality in many aspects of C2 decision making within both planning and execution phases of a mission. Consequently, this information represents a commodity that will be widely exchanged and employed in acquiring a shared, common awareness, a unity of action and a synchronization of effects.

The C2IEDM has been presented as an essential component in C2 interoperability, defining both a data model framework and exchange mechanism. It has been proposed that the advance of a consistent language and grammar, founded in doctrine would further advance C2IEDM's utility in the development of orders and extend its utility from planning to include execution [5, 13]. It has also been forwarded that advances in C2 automation demand that representations for information exchange include those necessary for use by other intelligent applications and decision aids. In aggregate, these qualities form the guidelines for the development and advance of a geoBML.

The C2IEDM provides an excellent framework for evolving the necessary elements of interoperable geo-environmental information and knowledge. Consequently, any geoBML should be organized as the necessary extensions to that framework meeting the conditions laid out in earlier sections of this paper. The wide range of geo-information application in C2 decision making also presents a sufficiently broad use case for advancing and validating the necessary element of: 1) a unifying language, 2) a vocabulary derived from doctrine which defines the appropriate contexts for use and 3) a grammar defining the syntactical structure of that information. Finally, a geoBML should comprise the necessary representations to support both human and machine reasoning and provide a semantic consistency that seamlessly compliments automated system output with human cognition and use. A geoBML developed around these principles advances the unity of Coalition C2 and the challenges that arise through net centricity, distributed decision making and the continued proliferation of automated and intelligent systems and tools.

1.4 Organization of the Paper

Section 1 provides an introduction to actionable geo-information for military operations. Terrain information, mission information and C2 information are introduced. Section 2 presents an analysis of actionable geo-information to make explicit the steps necessary to create actionable information from terrain data. In Section 3, previous work in this area, known as "Battle Management Language" (BML) is presented. Section 4 presents the concept of a Geospatial BML (geoBML), relates this to standard C2 semantics and gives an example of its use. Section 5 concludes with a discussion of future work.

2 The Domain of Geo-environmental Data, Information and Reasoning

In this section we first describe our view of how actionable geo-information is created from terrain data, then introduce the concept of relating this information to other C2 information. We conclude this section with a presentation of an innovative program that puts these ideas into practice to create terrain products.

2.1 Transforming Geo-environmental Data into Information

For the purposes of this discussion of a geoBML, there will be working definition and distinction between data, facts and information.

This distinction is made for the following reasons. Across the infosphere comprising C2 operations, there exist many specialty functions unique to data processing, analysis or reasoning and/or decision making (C2). Each specialty area has its own terms, references and processes codified in doctrine. For the purposes of this geoBML discussion and the central role of the C2IEDM in C2 interoperability, the geoBML focuses on the role of information for decision making. This information is tailored (abstracted) for individuals with a greater training and context in C2 and operations as opposed to data processing and lower level fact analysis.

It should be emphasized that even with the information focus of the geoBML, information alone is not sufficient to satisfy all requirements of the C2IEDM. The C2IEDM specifically calls for content from facts that are effectively represented in existing data models and dictionaries that largely address what is referred to in this discussion as facts (e.g. Theater Geospatial Database (TGD) [8] and Environmental Data Coding Specification (EDCS) [12] for terrain as well as the Joint METOC Brokering Language (JMBL) for atmospheric and weather).

Definitions used in this discussion and illustrated in Figure 1:

Data/Source: Raw sensor data (image or signal), existing non-validated cartographic feature data of natural and man-made phenomenon (surface and subsurface), Digital Elevation Models (DEMs), bathymetric, weather, atmospheric, climatological and other environmental data.

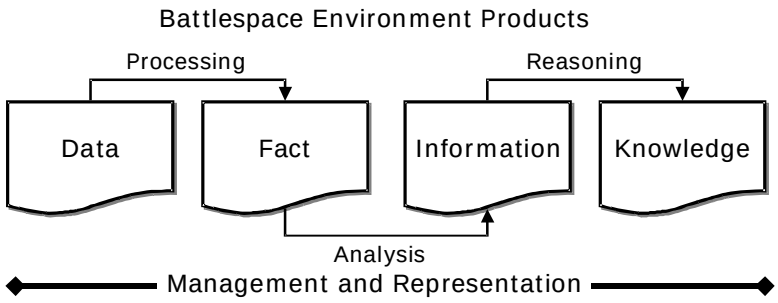

Figure 1: Information Value Chain

Fact: Validated, natural and manmade features where each feature or elevation value has known thematic and positional accuracy (x, y and z) in a specified representation. Validated, refined or post-processed environmental data with thematic and positional accuracy (x, y and z) in a specified representation.

Information: Tactical Decision Aids (TDAs) and analytic products that are fundamentally addressing spatial information of tactical and operational significance (military context). This information is general in nature as defined by traditional concepts of OAKOC – Observation and fields of fire, Avenue of approach, Key terrain, Obstacles, Concealment and cover, as well as positions of advantage, mobility and maneuver potential as well as weather effects on terrain state and signature physics. Greater specificity at this level of representation and content is accomplished by incorporating the tactical requirements of a force (echelon and type), performing a given activity or task (e.g. location suitability) given current and future environmental conditions. The incorporation of force and generalized task information provide the basis for both the links to appropriate elements of the C2IEDM for extension as well as the context for language development. Products at this level are designed to maximize utility and persistence.

Knowledge: These analytic products address spatio-temporal interrelationships of tactical significance and apply greater specificity of mission parameters. Knowledge products represent relationships with higher order (complexity) military command task, mission and possibly situational description and definition (e.g. force size, time constraints and aspects of concealment or cover). Analytic products become "knowledge", by extending a temporal or predictive component to the analysis and extending the analytic relationships to tactical intent within a task execution and event(s) as related to force objective or mission. It is proposed that this level of product, through the framework offered by the C2IEDM, has logical links to that model.

The ability to incorporate information and knowledge facilitates predictive awareness within the context of the original mission planning phase while maintaining responsiveness to dynamic changes in battle execution. A necessary condition for the abstractions of geo-information and geo-knowledge products is that they be "dynamic" and "smart". Dynamic and smart refers to the ability of the product to be responsive to changing situation and mission as contained in other reports and messages defined under the MIP and C2IEDM.

2.2 Defining Geo-environmental Objects in a Mission Context

All militaries incorporate a deliberate planning process beginning with an initial order, its iterative refinement at each echelon or element of the force to be employed, Course of Action development and analysis, validation of the plan and then its implementation in execution. The C2 process continues with dynamic Intelligence Preparation of the Battlespace along with level two and three fusion in an effort to maintain accurate predictive battlespace awareness. Comprehensively, these C2 operations occur simultaneously and at varying levels of fidelity. There are tremendous challenges in defining spatial objects capable of providing this flexibility. First, the objects should possess general through specific information to support the appropriate stage in the planning or execution process. Second, the articulation of an object must possess sufficient parameters and content for use of the product at multiple echelons. Third, both dimensions of the first and second qualities of a spatial object should be internally consistent to

facilitate coherence between simultaneous and echeloned activities with regard to the effects provided by terrain and weather. A fourth essential aspect is that the objects be of a size capable of exchange on tactical communication networks. The final challenge is to construct objects which maximize the persistence of their utility. This last challenge has two aspects. The first requires that dynamic weather impacts be represented appropriately at the object level for the task/unit/system dependent on this information. The second seeks to define object methods that respond to other tactical information (e.g. observations, reports).

The successful definition of spatial objects that satisfy these challenges must be addressed in a systemic approach. Fundamental in the evolution of the objects is the use of experience operators who can relate: 1) doctrine and terms (language and vocabulary), 2) the operational context of an object or product's use as it relates to an echelon of force type, mission or task (content), 3) the sufficiency of a product's use as a function of the underlying quality of geo-environmental facts (general to specific).

The systemic implementation of a robust set of objects becomes a hierarchy with an is-a and part-of dimensionality with explicit inheritance. Building from the fact level, the first tier of spatial objects represent general aspects of the military value of the terrain and weather (e.g. OAKOC). Upon this, other products such as the Combined Obstacle Overlay (COO), mobility corridors and mobility potential (platform specific) can be abstracted and spatially represented. The most specific object definition at Tier 1 analysis defines areas supportive of generalized deployment value (e.g. engagement areas, choke points or defensive positions) with an articulation of general optimal orientation. These objects might contain information regarding echelon of employment. However, they would not possess extensions that are highly mission or situation dependent. Finally, Tier 1 objects would hold parameters or methods characterizing the sensitivity of the object to predicted weather effects. As a general statement, Tier 1 products can be pre-computed and are to a degree, mission independent.

Tier 2 objects reflect objects from employing greater mission and task information. As the Commander's intent becomes more understood and the force package better defined, generalized deployment information can be made more specific defining positions of advantage for specific force type, echelon and task. Mobility corridors get defined as Avenues of Approach (AA) and may be further compartmented or organized as a function of its battlefield geometry and operational value (e.g. optimal for defense). Lastly, Tier 3 processing provide information objects that have greater situational qualities addressing the current state of battlefield participants, their location and orientation of action.

The complete set of information objects, evolved from accepted doctrine: 1) provide a meaningful structure for relationship to the C2IEDM, 2) provide a complex set of interrelated use cases for evolving a language addressing both planning and execution and 3) provide a unified representational foundation capable of supporting cognitive and automated processes.

2.3 Battlefield Terrain Reasoning and Awareness

The Battlefield Terrain Reasoning and Awareness (BTRA) program is designated as both a U.S. Army Science and Technology Objective (STO) and Defence Technology Objective (DTO). Initiated in FY02, BTRA consciously focused on analytic and decision technologies that convert facts to information and information to knowledge. In the enforcement of this philosophy, BTRA is creating a product line of explicitly defined and represented spatial objects, TDAs, and decision tools supporting C2 and military intelligence processes. This approach lends itself to a coherent knowledge management services for Mapping, Charting, Geodesy, and Imagery (MCG&I), terrain and meteorological reasoning and analysis capabilities. The hierarchical organization of BTRA allows for the tailoring of facts, information and knowledge as discrete elements consistent with the tiered structure defined in Section 2.2 BTRA's attention to product size and bandwidth utilization makes it objects appropriate for network dissemination at most tactical levels.

Consequently, the current and near-term efforts within geoBML will evolve from the structured baseline represented in BTRA. From this philosophy of organization, other partner's projects and investments in terrain and weather analysis should be capable of further extensions of the C2IEDM, the development of a language and ultimately a comprehensive geoBML.

3 Battle Management Language

BML is an emerging concept that is the formalization of warfighting doctrine into an unambiguous Command and Control Language. In Net-Centric Operations the intent of a commander is still the start of planning and executing a mission. It is more important than before that this intent be well structured and unambiguous. A persistent issue with the original BMLs has been the lack of formal syntax and semantics – in other words, the lack of a grammar. In the following section, we will describe the previous work done with BML and an initial effort at formal grammar development for military orders.

3.1 Battle Management Language Purpose

A major drawback of using computer-simulated training is the need for large contingents of support personnel to act as workstation controllers and provide the interface between the training unit and the simulation. The group of workstation controllers is often as large as, or larger than, the training audience. While this enables training opportunities at the corps and division echelon, it is still resource-intensive and lacks the degree of fidelity that actual combat operations present to the commander and staff. A standard representation and tools that can be used to automate the simulation interface are needed. A properly defined BML would address this need.

Each major simulation used today to represent military operational forces has a BML to task simulated units. Unfortunately, each of these is specific to its own simulation and often is driven by technical constraints of the simulation system and not by operational necessities of the warfighter.

Taking the widest possible interpretation, BML has been defined [4] as:

> ***The unambiguous language used to command and control forces and equipment conducting military operations and to provide for situational awareness and a shared, common operational picture.***

The objective of the BML work is to define an unambiguous language to describe the commander's intent in a way that soldiers and systems can understand and make use of it. The resulting language should be applicable not only to simulation systems, but also to operational command and control systems, and robotics.

In 2002-2003 SIMCI sponsored an Army BML Proof of Principle (PoP) demonstration, bounded by requirements to: 1) eliminate "free text"; 2) employ a realistic scenario; 3) use BML to link a C2 application to a simulation in a doctrinally consistent manner; 4) employ doctrinally correct tasks and units; and, 5) employ a scenario useable by both the C2 application and the simulation, thereby requiring a common terrain database [4, 5].

To meet these requirements, the SIMCI-sponsored demonstration employed a realistic scenario in which a heavy brigade with its supporting units conducted operations at the National Training Center, Fort Irwin, California. The demonstration contained four components: 1) a C2 application to develop COAs and generate orders; 2) a simulation, used to simulate the effects of orders generated by the C2 application; 3) a BML repository (using a "5W" representation – Who, What, Where, When, Why); and, 4) a graphical user interface to allow staff members to view BML-based "5W" orders and create orders for subordinate units whose missions were subsequently carried out in the simulation.

The result of this effort was a series of successful BML PoP demonstrations to senior Army leaders in 2003-2004, generating enthusiasm and sanction for additional development of BML concepts. From a combatant commander's perspective, the importance of the BML PoP is in the demonstration how the functional requirements can be met, thus paving the way for a viable COA analysis and mission rehearsal tool. The SIMCI-sponsored work was the foundation for several other BML initiatives with Air Operations [17] and Coalition Forces [9] as well as the following initiatives.

3.2 Current Coalition Initiatives

The Simulation to Command and Control Information System Connectivity Experiments (SINCE) program is investigating interoperability issues by conducting multinational C2 experiments, supported by C2 and Simulation systems, designed to address the transformation of collaborative planning and interoperable execution in a coalition environment [11].

Within SISO, the Coalition BML (C-BML) Study Group was formed in September 2004 to investigate the concept of BML. The Study Group consisted of participants from 11 different countries. After the Study Group published it's final report in September 2005 [3], a Product Development Group (PDG) was formed to standardize BML.

In parallel to the C-BML Study Group activities, the NATO Modeling and Simulation Group (NMSG) established a 12 month Exploratory Team (ET-016) on C-BML [3, 15, 16]. The team, led by France, endorsed the requirement for a C-BML and has proposed that a 3-year Technical Activity Program should be established. Their recommendation was submitted to a meeting of the NMSG in October 2005 in Poland and a NATO Technical Activity (MSG-048) has been approved for 2006-2009.

3.3 A BML Grammar

BML work has concentrated on leveraging standard data model semantics (particularly Multinational Interoperability Programme's (MIP's) Command and Control Information Exchange Data Model – C2IEDM) as well as on the 5 Ws (WHO, WHAT, WHERE, WHEN and WHY) for a SISO C-BML specification. However, an explicit formal grammar is needed to enable a) automatic language processing, b) the calculation of an expression's meaning out from the meaning of its parts, and c) the expressiveness required by BML.

The format of orders is defined by the NATO standard STANG 2014 "Format for Orders and Designation of Timings, Locations and Boundaries." An Operational Order is divided into five sections 1) Situation, 2) Mission, 3) Execution, 4) Administration and Logistics, 5) Command and Signal, and the respective annexes. For conveying the essence of an order to a simulation system, Section 3 is currently the most applicable given the behaviors available. Section 3 will "summarize the overall course of action," "assign specific tasks to each element of the task organization," and "give details of coordination." In the following, we briefly summarize the types of production rules needed to generate and to parse a formal BML grammar. More detail is given in [13].

In order to provide an impression how the grammar looks like, the following introduces the grammar's basic rules for orders as well as some of their sub-rules. In general, according to the principles we presented before, grammar rules are composed of a terminal symbol and its frame. Basic rules consist of a tasking verb – Verb, taken from C2IEDM's table "action-task-activity-code" – as terminal symbol and a respective verb frame. Their general form is given in (1a) whereas (1b) and (1c) present explicit examples.

(1a) B → Verb Tasker Taskee (Affected) Where
Start-When (End-When) Why Label (Mod)*

(1b) B → ***advance*** Tasker Taskee Route-Where
Start-When (End-When) Why Label (Mod)*

(1c) B → ***block*** Tasker Taskee Affected At-Where
Start-When (End-When) Why Label (Mod)*

In these rules, Tasker is a non-terminal to be expanded by the name of the one who gives the order, Taskee is to be expanded by the name of the unit that is ordered to execute the task, and Start-When and End-When are to be expanded by temporal phrases. Tasker, Taskee, Start-When, and End-When appear in each basic rule. Affected is to be expanded by an identifier of the unit to be affected by the task, in case of ***block*** an enemy unit. Whether Affected is part of a rule depends on the task. Affected is there if the task's frame requires it. The same is true for Where. It is either an At-Where or a Route-Where as determined by the task. Where has to be expanded by

location phrases. These expansions are complex. E.g., Route-Where can be expanded to "***from*** Location ***to*** Location ***via*** Location ***and*** Location". Some of the respective rules are given in (2).

(2a) Route-Where → (Source) Destination (Path) | … | ***along*** Route

(2b) Source → ***from*** Location

(2c) Destination → ***to*** Location

A basic rule ends with the non-terminals Why, Label and the optional Mod. Why represents a reason why the task is ordered. Label is expanded by a unique identifier. By this identifier the single order represented by the respective basic expression can referred to in other expressions – it functions like a personal pronoun. The optional Mod (for modifier) is a wild-card that represents additional information necessary to describe a particular task, e.g., formation – to specify a particular formation for an advance.

C_Sp → Control_Feature Tasker (Taskee) Start-When (End-When) Label

The spatial coordination rules correspond to the basic rules in their form. The key words denote control features, e.g., lines or areas. These are taken from C2IEDM's table "control-feature-type-category-code." In this case the area of responsibility is assigned by a commander to be used by a subordinate and is considered an area well defined by natural features or control measures for the exclusive operation of the subordinate unit's forces. However, a hazard area is identified by a unit, but not assigned to a subordinate unit, hence there is no Taskee argument.

The abstract rule for temporal coordination is:

C_T → Temporal-Term Qualifier Action Action

In temporal coordinations, the non-terminals Action have to be expanded by different unique identifiers that serve as labels for basic expressions. Temporal-Term is either **start** or **end** signifying whether the start or the end of the first Action is determined by the expression. Qualifier is expanded by a relational expression that determines how the start (or the end) of the first Action is related to the temporal interval the second Action defines., Qualifier2 is taken from C2IEDM's table "action-temporal-association-category-code."

Exmples of BML rules used for formalizing orders are given in [13], Appendix A.

4 geoBML – A Geospatial Battle Management Language

A geoBML builds upon the BML work presented in Section 3. A key goal of geoBML is to make available actionable geo-information products from a computational level to the C2 processes in the same conceptual framework. Currently, geospatial products are created using varying techniques and procedures resulting in fundamentally different representations and processes than are used in the C2 planning process for forces and equipment. These inconsistencies result in a non-uniform context regarding geospatial impacts on C2 processes.

4.1 Concept

The C2 community has evolved a concept of a Battle Management Language (BML) to ensure explicit meaning and context between commanders. The explicit meaning (semantic) provided a common context through which two or more commanders (in different locations) could effectively and accurately communicate and collaborate on the state of the battlespace. The effectiveness of any communication between two or more elements is directly related to the shared, commonly defined context among the participants. BML provides the precision of context required for accurate shared awareness between commanders. There are two central tenets that lead to a geoBML:

- Its formalism did not include an *explicit* geospatial, terrain, weather or other environmental data component.
- BML was developed for data, information and knowledge exchange and sharing *between humans*.

These two conditions point to voids in capability as we move forward with Network-Centric concepts. The absence of an explicit geoBML to provide context and precision during interactions, transactions exchanges could lead to a less than optimal assessment of information leading to diminished shared awareness and understanding. This condition within a networked, distributed force dependent upon information superiority could be a critical point of failure. Second, the proliferation of automation, systems and devices as well as the emergence of system of systems (SoS) C2 architectures demands that the same formalism and explicit meaning of a BML be extended beyond the cognitive domain (for humans) to the information domain for automated systems and devices. The development of a geoBML and its attention to explicit modeling and representation for both warfighters and systems will dramatically improve shared awareness throughout the force, particularly edge elements closest to the physical domain and the fight. As stated, BTRA has been constructing the conceptual framework for communicating the terrain and environmental context of battle management, a theoretical geoBML if you will, but it is now necessary to go far beyond the traditional view of automated terrain support tools and create explicit concepts and representations of terrain and environmental relationships and effects among all aspects of intelligence gathering, situational awareness, and battle management.

geoBML concerns itself with the quality, characterization and utility of environmental information products, services and decision tools to achieve coherence of execution across nodes (e.g. units, platforms, systems, soldiers and edge devices) and participants of the networked force (e.g. geoBML). geoBML addresses issue of the “network and nodes” from the standpoint of how to best incorporate environment information and services to support edge elements.

4.2 geoBML in the C2IEDM

Since BML is built upon shared C2 semantics, there must also be a representation of environmental effects and concepts in the C2 lexicon for geoBML. The lexicon for implementing BML is the C2IEDM. Typical environmental data is stored in a Geographic Information System (GIS) that has a quite different data structure than the C2IEDM. Thus the implementation of geoBML will be the extension of existing concepts (such as the Control Measures Entity in the C2IEDM) and the creation of new concepts to support the planning process with terrain products.

4.3 Example

An example of geoBML providing power to the edge can be seen in the following Operational/Tactical vignette.

A coalition/multi-national corps has been tasked with a mission to enter a disputed territory and be prepared to conduct defensive operations to secure the area; offensive operations to restore previously established borders; and humanitarian relief and nation building operations in order to stabilize the area.

Within this organization and operational mission structure there will be a plethora of diverse units and missions all functioning at the edge and demanding very specific sets of information and tailored knowledge to support their tactical missions and tasks. Within the standard military construct of Mission, Enemy, Terrain and Weather, Troops and Support Available, Time Available and Civil Considerations (METT-TC) information and knowledge pertaining to Terrain and Weather will be of critical importance to virtually all of the decision making that needs to occur.

In the past most of this information was gleaned locally from low fidelity sources such as maps, limited reconnaissance's, long range forecasts or generalized descriptions of terrain and cultural features. Current systems now allow for the rapid development of significantly higher fidelity and more current and accurate technical products that can be used to support the diverse decision making requirements presented above. The problem, however, is that many of these products in their raw form are very technical in nature and do not transmute directly into the vocabulary or form of the decision maker's processes. Additionally, they also consist primarily of data and facts and not the information and knowledge that the operator at the edge requires in order to have a thorough understanding of the situation and make well informed, timely decisions. BTRA and geoBML provide the conduit that will now put tailored knowledge in the hands of those at the edge.

Underlying BTRA and geoBML is a concept of the Spatial Objects (SOs) that are arrayed in three tiers.

Tier 1 constitutes those SOs which are based exclusively or primarily upon the terrain and can be pre-computed without being informed by the other factors of METT-TC. Examples are:

- Cross County Mobility; Obstacle; Cover and Concealment SOs
- Fields of Fire and Dead Space SOs
- Maneuver Networks
- Mobility and Choke Point SOs

Tier 2 SOs are those that might support a certain mission or tactical task, but are based upon a strong set of terrain attributes and for which candidate SOs can be pre-computed. Examples are:

- Assembly Areas
- Attack By Fire Positions
- Avenues of Approach
- Engagement Areas
- Indirect Fire Firing Positions

Tier 3 SOs are very specific objects that have been selected to support a specific Course of Action (COA) and are associated with a plan or order. In many cases they have been chosen from the Tier 2 candidate SOs and been further refined based upon METT-TC. They may also include graphic control measures and other items that are often associates with or influence the perception of terrain. Examples are:

- Assembly Area
- Attack By Fire Position
- Battle Position
- Boundary
- Engagement Area
- Indirect Fire Firing Position
- Man-made obstacle
- Minefield
- Phase Line

Some of the Tier 1 products are composed primarily of facts and data and are used to compute other Tier 1 products, e.g. the maneuver network and obstacle graph are used to produce the Mobility Corridor and Choke Point SOs. The Tier 1 products are then often used to compute Tier 2 products and refine them into Tier 3 products.

geoBML allows for these SOs to be defined, described, stored (either as objects or representations of the objects) in the C2IEDM and made readily available to the diverse decision makers. Figures 2 – 5 show a representation of certain Tier 1 products that can be developed in BTRA and provided to the edge.

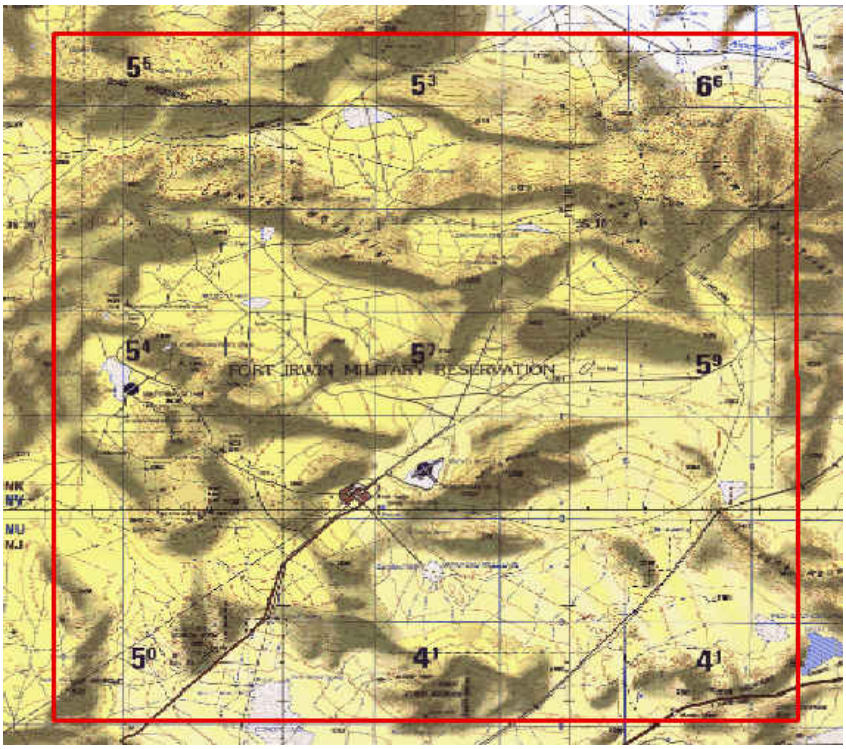

Figure 2: Represents the notional Area of Operations (AO) in which our Coalition/Multinational Corps will be operating.

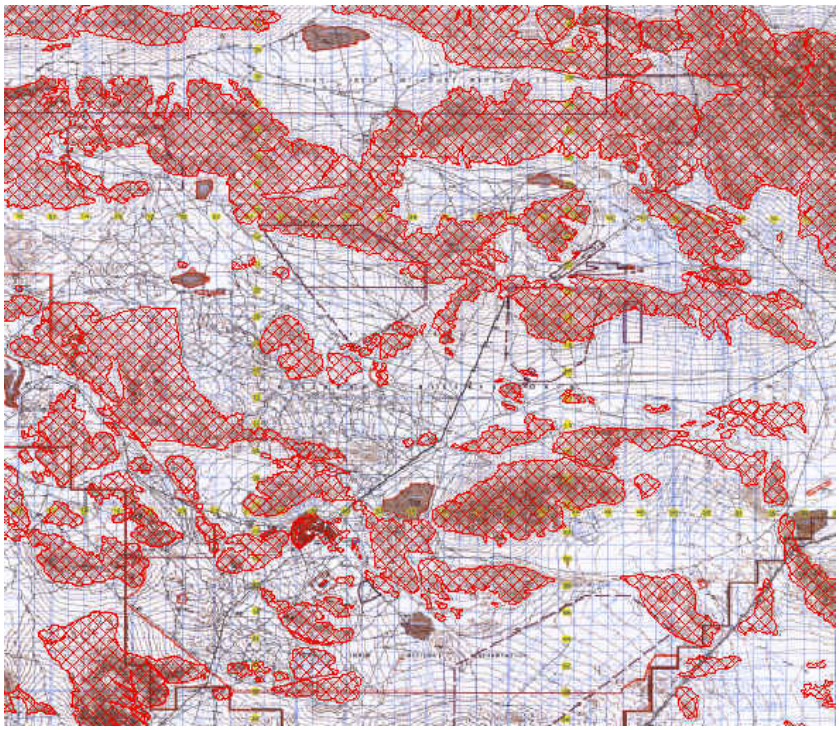

Figure 3: Obstacle Spatial Object for the AO

Figure 4: Maneuver Network Spatial Object for the AO

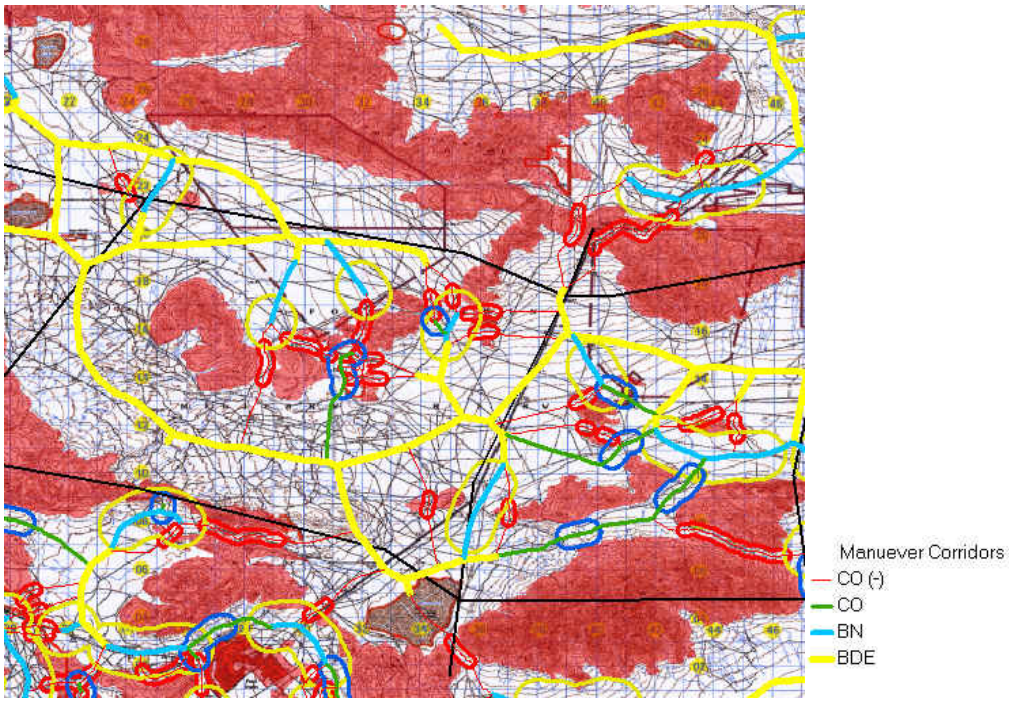

Figure 5: An integrated Graphic Showing the Mobility Corridors and Choke Point Spatial Objects by Echelon

A maneuver commander within the above mentioned multinational force might be tasked to conduct an attack to dislodge opposition forces that have made incursions across the previously established borders, and then establish a line of defense to secure the area. In this case the commander would evaluate the above Tier 1 Mobility Corridor Spatial Object, in conjunction with an enemy forces overlay, and establish Avenues of Approach to his objectives. He then in turn would call for a series of Tier 2 Spatial Objects that would cover the following potential battlefield items do support his attack:

- Assembly Areas
- Indirect Fire Firing Positions
- Engagement Areas
- Attack By Fire Positions

These Tier 2 Spatial Objects can then be evaluated in conjunction with the non terrain factors of METT-TC and assist in the rapid generation of various Courses of Action (COA's). As specific Tier 2 SOs become incorporated into COA's they become Tier 3 products and can be iteratively refined using BTRA in order to support specific units and weapons systems. Once a specific COA is selected it becomes associated with a given plan or order within the C2IEDM. Other commanders that are responsible for combat support and combat service support would use both the mobility products and other SOs that are tailored specifically to their Battlefield Operating Systems in a similar manner. Both geoBML and the C2IEDM are used to transmit and store these Spatial Objects in a form and fashion that is native to the operator.

The above graphics show a representative set of Tier 1 Spatial Objects that could be pre-computed in BTRA and made available through geoBML to all operators at the edge. Regardless if one is a maneuver commander tasked with planning and executing offensive and defensive operations; a combat support commander planning the support of all of the potential operations within the AO; or a hospital commander planning for the evacuation of wounded and the establishment of regional medical support clinics for the local populace, this information is important and available to each.

5 Conclusions

In this paper we have described a new approach to the representation of environmental information and knowledge in a multi-level computational model that organizes computable objects for aspects of Intelligence Preparation of the Battlespace, Level Two and Three Fusion and anticipatory or Predictive Battlespace Awareness that have not previously been represented in a computational form. Through this approach, environmental battlespace context can be applied to automated C2 tools that perform geospatial and temporal reasoning across nodes of the networked force. This will facilitate a balance to traditional geospatial constructs centered on visualization and manual methods.

5.1 Using a geoBML in Coalition Planning

The most effective BML will serve not only in its current C2-Simulation role, but also to support communication among C2 systems. Our initial work in coalition BML indicates that this principle applies also to coalition C2 systems, where communication generally is stressed and the

ability to simulate a plan to validate its effectiveness can enable more effective operations [10]. Expanding BML to incorporate geoBML only increases the validity of this principle in that the C2 planning process and its evaluation via simulation become much more effective where the effects of terrain can be incorporated with high accuracy.

5.2 Future Work in Implications of BML in the Service Oriented Architecture Environment

A major area of required future effort is analysis of the implications of geoBML for the emerging Service Oriented Architectures that are projected as the basis of interoperability for future DoD networked systems. While highly attractive from a standpoint of composability and rapid development, SOA have serious unresolved issues regarding trustworthiness and efficiency. The large data flows associated with geoBML will stress efficiency, particularly in tactical networks, while the need for rapid assembly of systems using geoBML will stress the degree to which trustworthiness can be predetermined.

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