Geospatial Battle Management Language: Bridging GIS, C2 and Simulations

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Abstract

The Command and Control (C2) of military forces now relies primarily on digital systems. Battle Management Language (BML) is the unambiguous language used to command and control forces and equipment conducting military operations and to provide for situational awareness (SA) and a shared, common operational picture. Terrain and weather effects represent fundamental aspects of the battlefield supporting SA and the decision-making processes within the C2 domain. Geospatial Battle Management Language (geoBML) is an extension of BML into the domain of actionable geospatial information and provides a semantic and syntactic bridge between the terrain experts' realm and the Warfighter's decision-making and SA needs. Current geoBML development efforts incorporating C2, GIS and supporting simulation systems have highlighted significant issues and potential solutions that arise with operations planned using real-world terrain data and executed within a Modeling and Simulation (M&S) environment utilizing virtual representations of terrain and weather.

1 Introduction

1.1 Background

Over the past decade there has been a significant shift in the conduct of exercising military Command and Control (C2). While many of the underlying processes, such as the Military Decision Making Process (MDMP), remain valid and well used, the technology, tools and many of the supporting processes that enable C2 have experienced a significant revolution. In 1997 the US Army was just embarking on a series of digital warfighting exercises in order to determine if and how it could best develop and field its automated Army Battle Command System (ABCS) in order to "digitize" the force. Today, as a result of war driven necessity and technological advancement virtually every Army element, from squad to the Combined/Joint Land Forces Component Commander (C/JFLCC) is operating in a digital environment. This also extends to the Air and Maritime Components, many allied armed forces and even into the realm of governmental Inter-Agency operations and Non-Governmental Organizations (NGOs).

One of the greatest technical advances in the area of supporting dynamic C2 has been the ability to collect, analyse and manipulate geospatial data. Unfortunately, the methods and processes for requesting, focusing and distributing these products in relation to the needs of the Warfighter have not progressed as rapidly. Recently Hieb et al [1] proposed a common framework for integrating command and control systems, geographic information systems and simulations. In that paper they laid out both the potential and the problems that currently exist in bringing these various domains together in support the Warfighter and explained how their proposed framework can resolve this issue. In this paper we discuss an ongoing research project aimed at implementing this framework and determining the best approach for developing products and process that will provide actionable geospatial information to the Warfighter in the most effective and efficient manner. Central to this research program is the use of ArcGIS and the Commercial Joint Mapping Toolkit (CJMTK)

Within the US Department of Defense (DOD) a driving force for the thrust in advancing C2 is the Command and Control Research Program (CCRP) within the Office of the Assistant Secretary of Defense, Networks and Information Integration (OASD/NII). It is the program that is leading the move from "Industrial Age C2 to Information Age C2" [2]. While all of the services are developing their architectures, equipment and capabilities to work within DOD's construct of Network Centric Warfare (NCW)/Network Centric Operations (NCO), the actual Warfighters continue to stress that the developers must ultimately remain focused on supporting the human aspect of C2. "The commander must be the focal point of decision making and execution within military operations. The role of the staff—and supporting technological aids—is to support the commander in achieving situational understanding, making decisions, disseminating directives, and following directives through execution." [3] As part of its doctrinal underpinnings for the exercise of C2, and the development of supporting systems, the US Army relies on the concept of a "cognitive hierarchy" as explained in Figure 1 from FM 6-0. [4].

Thus, the concept of a human focus based upon the "cognitive hierarchy" provides a framework for developing future systems for supporting C2 or "Battle Command" as it is commonly referred to. In this case when we talk about systems development we include not only the hardware and software components, but also the products that are generated, the input data sources and the processes that are used to support the commander as well as the requirement for a common, unambiguous language used to invoke the system.

COGNITIVE HIERARCHY
Information, in the general sense, is the meaning humans assign to data. The cognitive hierarchy defines four different levels of meaning. A principal task of information management (IM) is to collect information and transform it by adding progressively greater meaning at each level of the cognitive hierarchy. This process raises information from the lowest level, data, to the highest, understanding. With understanding, commanders can make better decisions and more effectively regulate actions by their forces. Each level of information has a different value in supporting command and control (C2). The distinctions between the levels of the cognitive hierarchy are not always clear. However, it is important to realize that they exist.
[from FM 6-0]

Figure 1: Cognitive Hierarchy

While it is important to note that the concept of NCW/NCO provides a unifying basis for future development, it is equally important to recognize that what we have today is not the product of a grand and unifying design, but the convergence of a multitude of concepts, programs, capabilities and products that is ever evolving. In fact our current "system of systems" has been referred to as a "serendipitous" evolution of these various aspects, which by definition indicates that the results are unplanned and significantly influenced by chance. As we move forward we intend to reduce the aspects of "serendipity" and replace them with informed design and structured development supported by rapid prototyping and operational experimentation with the Warfighter in the loop.

The focus of this paper is on the development and initial use of Geospatial Battle Management Language (geoBML), one very critical facet of support for active C2/Battle Command within the framework discussed above.

1.2 Organization of the Paper

Section 1 provides an introduction to current and evolving realm of military Command and Control. Section 2 provides a background regarding some organizing concepts for Army Battle Command; discusses the development of an Operational Battle Management Language (BML) that is required to fully move into the "digital age" and then the concept for geoBML as a logical extension of BML. Section 3 lays out the technical and operational implementation of geoBML, Section 4 discusses the implementation with a supporting simulation, Section 5 presents conclusions, Section 6 provides acknowledgements and Section 7 contains the references.

2. Battle Management Language

2.1 Background

In 2001 the Department of the Army's Simulation to C4I Overarching Integrated Product Team (SIMCI-OIPT) initiated the Battle Management Language program. BML's underlying concept is to enable direct communications between Army Battle Command Systems (ABCS) and simulations. BML's goal is to enhance and enable ABCS capabilities along several lines. First, to create a clear, unambiguous language that supports communications between humans, automated systems and future robotic forces. Second, to dramatically improve commander and battle staff training on ABCS by reducing the training "overhead," and third, by facilitating simulation-based planning and decision support using automated C2 tools. In 2001 the program consisted of concepts development and program design. In April of 2001 the TRADOC Program Integration Office ABCS (TPIO-ABCS) co-hosted a BML users' conference at the Combined Arms Center. This conference came to a unanimous agreement that there is a pressing need for a functional BML, which is described by Carey et al [5].

The formal definition of BML is "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". In its current state it is primarily a spoken and written language used by humans for interpersonal communications. Within that context the current BML development program is aimed at further developing and configuring this language so that it can be embedded in standard Command, Control, Communications, Computers, and Intelligence (C4I) components and allow commanders and staffs to interact directly with supporting models and simulations. In the future this enhanced BML will also serve as the basis for communicating with any robotic elements that might be developed and deployed. Additionally, BML will facilitate the clear and unambiguous communication between various echelons of command and, in particular, between various Services and Joint/Combined headquarters. BML will continue to be derived directly from approved doctrinal sources and will be familiar and implicitly useable by the experienced military professional. It is NOT a programming language.

2.1.1 BML Concept

The development of a BML will enable direct interaction between standard Army C4I components and supporting M&S applications. As transformation of the forces occurs, communication of command and control (C2) information is increasingly handled by digitized systems. As such, not only are humans consuming this information but also more and more automated processing and support systems are doing so (Figure 2). Most recently there has been a need to use simulations to stimulate and be stimulated by the C4I systems. Thus, this communication is becoming less interpersonal and more data oriented. The most critical C2 information, the commander's intent, orders and directives, however, does not currently flow as data. It is communicated as 'free text' elements within messages or as stand-alone files. While suitable for interpersonal communication, it is inadequate for use with simulations, or for the future forces that have robotic components. The most difficult part of this problem is transmitting the Operations Order (OPORD) across to implementing/executing Simulations. Currently, the OPORD is transmitted in the standard five-paragraph format but the content of the individual paragraphs is largely free text. Dealing with free text is not a problem for trained, experienced Soldiers/Marines in the training audience. Developing simulation components that have the knowledge necessary to comprehend and process the intricacies and nuances in

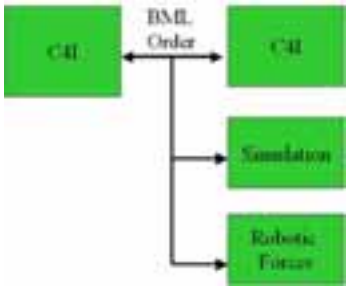

Figure 2: BML Scope

an OPORD is a major challenge. A broad based BML was proposed to address this situation. The BML will explicitly communicate mission-type orders to Simulations without requiring the commander and staff to become computer programmers. It will use the Service's doctrinal language.

The concept is to incorporate the doctrinal base into the C2IEDM/JC3IEDM (described in section 3. below), which will be used to exchange C2 information in future Army C2 systems. This doctrinal base will include the vocabulary as contained in FM 1-02, Operational Terms and Graphics as data tables. The syntax and semantics as defined through the Army Universal Task List (AUTL) (FM 7-15), the Army Training and Evaluation Program (ARTEP) Mission Training Plans (MTP) and the other related Field Manuals will be used to define the relationships of the data tables with respect to specific echelon and type units. This will allow the user of the C4I systems to operationally specify the required actions and behaviors that are to be executed by the subordinate units, either live or simulated, and provides for a detailed mapping to specific execution code within models and simulations. Likewise required feedback from these models and simulations will be posted to the supporting C4I systems as database updates and standard reports. With the vocabulary and its associated relationships built into the database, graphical user interfaces (GUI) and other applications can be constructed that allow implementation of the BML. One such interface is the BML GUI which was developed to allow the data formatted order (message) to be displayed in a format familiar to the military operator.

Several advantages result from this approach.

- Building the vocabulary into the database allows for exchanging information through data replication and technologies such as eXtensible Markup Language (XML).
- The terms, as they are used in messages, can be linked to their doctrinal definitions to assist users (senders and receivers) in understanding the precise intent of the author. This can be extremely helpful in those areas where a term has multiple definitions or there are subtle differences in the meanings of different terms. In this way, the terms become codified in the standard C4I Databases and BML will be familiar and easy to use by operational forces. BML will be the medium that soldiers use to "communicate", essentially talk to Simulations. Additionally, because BML is doctrinally based and in consonance with the AUTL, it is being designed to accommodate Joint and Combined operations. This is extremely critical when communicating missions, tasks and desired effects between Services and allied forces.
- As the work continues to align the data models among simulations and C4I systems then the approach of building BML into the JC3IEDM, will lead to better alignment/adoption of a single BML for multiple domains.
- Ensuring that the database includes the graphics as well as the terms will assist in transitioning from course of action development and analysis tools linked to the database to producing the operations order. It enables this as either an auto fill of structured formatted messages, or as a GUI-based representation of the current situation and operational objectives.

2.2 Geospatial BML as and extension of BML

The US Army utilizes a number of organizing concepts in order to guide the conduct of operations and the development of supporting doctrine, systems, processes, and organizations. One of the most prominent of these organizing constructs is that of the Warfighter Functions (WFFs). "A warfighting function is a group of tasks and systems (people, organizations, information, and processes) united by a common purpose that commanders use to accomplish missions and training objectives."[6] The WFFs are:

- Movement and maneuver
- Fires
- Intelligence
- Sustainment

- Command and control
- Protection

Formerly the WFFs were known as Battlefield Operating Systems (BOS) or Battlefield Functional Areas (BFA) which relate directly to the current WFFs as indicated in the chart below (Figure 3).

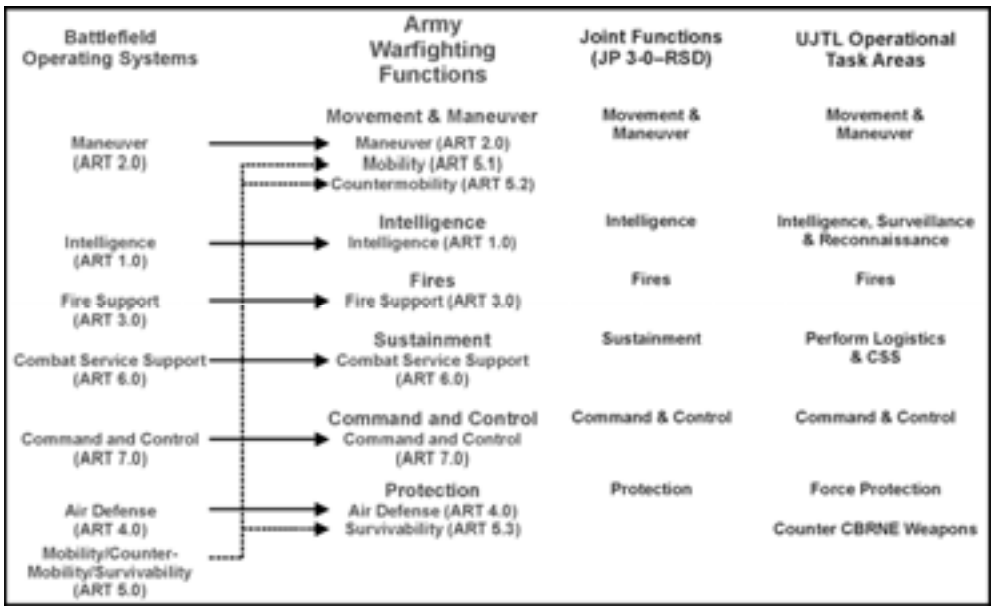

Figure 3

When the Army developed and then revised its Army Universal Task List (FM 7-15) it organized these tasks around the concept of the BOSs with the result being that we have an ability to create a true alignment between the missions, tasks and supporting systems and processes that are used to conduct military operations. Within both the BOSs/WFFs the function of Command and Control is considered the integrating function and BML and the supporting C2IEDM/JC3IEDM are explicitly designed to support the C2 WFF. A variety of specialized automated systems have been developed within the other WFFs in order to support those WFF specific responsibilities and processes. In most cases the databases, protocols and machine languages of the various systems provide limited interoperability with the other WFF systems. The Digital Topographic Support System (DTSS) is designed to support the Mobility/ Countermobility/Survivability BOS. DTSS utilizes the full suite of ArcGIS with ARCINFO license. ArcGIS is its primary application software for vector products and ERDAS Imagine is its primary application for raster image analysis and map production and printing and it utilizes multiple geospatial databases. Current C2 systems do not necessarily have geospatial databases and may have only a limited Geographical Information System (GIS) capability.

The Battlespace Terrain Reasoning and Awareness (BTRA) program, detailed below, is an Army Technology Objective (ATO) research program developed and managed by the US Army Corps of Engineers' Engineering Research and Development Center's (ERDC) Topographic Engineering Center (TEC). It is designed to bring tailored, actionable geospatial information into the hands of the Warfighter. In order to enable this capability Battle Management Language was extended, via geoBML, creating a semantic and syntactic bridge between the highly specialized domain of terrain reasoning and analysis and the immediate needs of the operational Warfighter. Further reading on the subject of geoBML is available in the papers by Hieb et al [7], [8], [9].

2.3 BTRA Background

The core purpose of Battlespace Terrain Reasoning and Awareness (BTRA) is to provide software applications and a framework to transform the copious amounts of high-fidelity data produced by terrain teams and air or ground sensors into tactical decision aids or data products that provide a deeper understanding of the battlefield and how terrain and weather effects can constrain tactical operations and equipment platforms. They accomplish this by harnessing the geoprocessing algorithms and libraries that reside in the Commercial Joint Mapping Toolkit (CJMTK). BTRA aggregates data and their associated analytical processes from three main areas – terrain, weather, and sensor performance.

The effects of terrain are defined in military doctrine by the acronym OAKOC – obstacles, avenues of approach, key terrain, observation and fields of fire, and cover and concealment. Simply put, terrain constrains where a unit or weapons platform can go and what they can see. Terrain analysis can tell us what routes units should take to avoid natural obstacles, or to avoid detection by maximizing concealment, or a combination of such various factors. It can even tell us what sites might be appropriate for indirect firing positions or landing zones based on the slope, aspect, and elevation of the candidate position and the surrounding terrain. Thus, the commander must know the terrain aspects of the battlefield to gauge the effectiveness of tactics or strategies at his disposal which in turn begins to refine his plan of action.

Weather constrains tactics and strategies in much the same way as terrain but with the additional challenge of being temporally dynamic. Routes that are trafficable during a hot, dry day may mire vehicles when soaked with rain. Range of observation can be diminished through fog, precipitation, or cloud cover that masks the sun or moon. Aerial units may want to fly at a certain time of the day to avoid forecasted inclement weather. Weather effects may also be described by the time nature of exposure to weather such as temperature extremes. The key, however, is to synchronize the effect of weather based on where a unit or weapons platform is within the weather grid, what time it will be there and for how long.

Sensor performance analyzes the impact of the interactions between terrain and weather on target detection or acquisition. This is important not only for special reconnaissance units such as a UAV or long-range surveillance team, but also for those weapons platforms that rely on optics and imaging sensors to track the enemy. For example, certain sensors may not be able to operate in extremely cold environments or their effectiveness is reduced if the ambient temperature is within a tolerance of a target's heat output.

BTRA is a collection of software applications loosely coupled through a common data model that produce standardized data products grounded in military doctrine. There are three key implementation concepts to BTRA: the use of the Commercial Joint Mapping Toolkit (CJMTK) for its terrain analysis functionality and as a baseline for managing spatial or spatially related data, the linking of software applications via a common base data model and a framework for describing the resulting decision aids or data products, and the use of data sources that are currently in operation (such as the Theater Geospatial Database, or TGD) and/or available that provide the necessary level of attribution to support terrain analysis.

CJMTK is a COTS-based geographic information system (GIS) that utilizes ESRI's ArcGIS line of products to serve as the primary source for terrain analysis or geoprocessing functionality for the current and future force. This functionality is encapsulated in C++/COM libraries known to CJMTK/ESRI developers as ArcObjects. These ArcObjects can perform a myriad of functions, from raster analysis to network or graph creation and analysis to route solving using various algorithms. Since most databases were not constructed with spatial or spatially related data in mind, ESRI also developed the concept of the geodatabase - a specialized database with tables and fields to manage the raster or vector data stored within. Access to the geodatabase is abstracted by the ArcObjects API so that different database vendors or database formats may be used interchangeably.

Although its widespread adoption is proceeding apace, the rich set of terrain analysis tools and algorithms that CJMTK contains has barely been leveraged to perform anything more than serve up maps as a reference for the location of friendly or enemy units. BTRA seeks to expand this narrow paradigm by exploiting the geoprocessing tools and libraries shipped with CJMTK to quickly and effectively translate the results of specialized and sophisticated analyses from the exclusive domain of terrain specialists into the operational and tactical lexicon of the field commander and the command staff. Additionally, since the BTRA applications are based on a toolkit that is poised to eventually become ubiquitous within the C2 community, BTRA and terrain analysis in general will be similarly positioned to enhance the capabilities of the current and future force.

The common base data model consists of tables within a geodatabase and is an aggregate of data processed from various sources such as TGD, Digital Terrain and Elevation Data (DTED) rasters, weather from IMETS, or IR profiles from deployed sensors. The foundational data model is then used to derive standardized data products, termed tactical spatial objects (TSO), which are linked to military operational tasks and take into account the effects of terrain and weather thus turning raw data into knowledge about the battlefield. These TSOs are defined by subject matter and operational experts, grounded in military doctrine, and can serve as the basis for further terrain analysis by other specialized BTRA tools and/or as the final result to be linked back into the operational and tactical domain. For the last reason, the TSOs are grouped into tiers based on certain characteristics. Tier 1 TSOs represent the general military value of the terrain and weather based on the doctrinal principles of OAKOC – obstacles, avenues of approach, key terrain, observation and fields of fire, and cover and concealment. These data products can be pre-computed and are generally mission independent. Tier 2 TSOs can be derived from the foundational data and/or from analysis of Tier 1 TSOs. They are more tightly integrated with the tasks that are required to support the unit's mission or operations and are generated when that information becomes available or is further refined. Tier 3 TSO's are increasingly mission and task focused while also accounting for specific friendly and enemy situations.

The common base data model and the standardized tactical spatial objects produced from it encourage reuse across time and space. Units that are deploying to a region can seek out previously generated data products for initial reconnaissance or analysis or if they find that there are none or if more updated data is available, generate their own – thus creating a set of institutional battlefield knowledge that can be rapidly assimilated and understood. Additionally, because the TSO's are grounded in military doctrine, they have a shared and unambiguous meaning across the force. And since raw data or data located in other databases need to be processed into a common base data model, BTRA can use different sources while maintaining a stable codebase for its analysis tools.

Locating data sources with the necessary level of attribution or resolution in order to perform a reasonable terrain analysis is a constant work in progress. BTRA aims to remain operationally relevant to the current and future force by utilizing data sources that have been developed for and actually used in the field (such as TGD) or are primary sources produced by other government agencies (such as DTED).

The maneuver network generator (Figure 4) is an example of a tool that creates a Tier 1 tactical spatial object that is used for further analysis by downstream tools. The tool uses feature data stored in the base data model and constructs a graph of all possible trafficable routes within an area of operations. Attributes attached to each edge enumerate characteristics and costs such as the width and base speed. This network can then be used in conjunction with up-to-date weather data and standard mobility models for different vehicle classes to calculate more accurate costs if an edge is selected for a route.

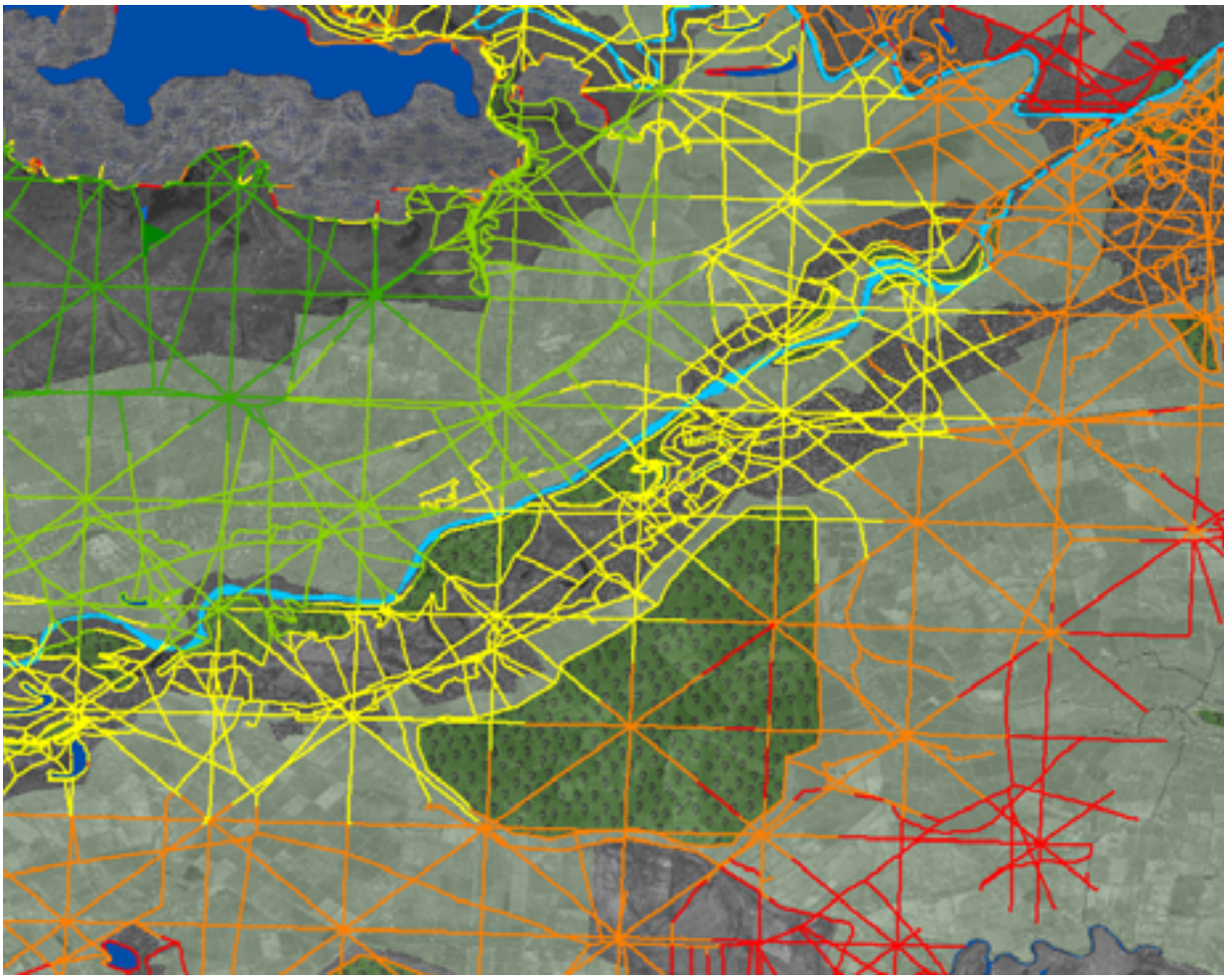

Figure 4: Screenshot of Maneuver Network Spatial Object

The movement projection tool is an example of a tool that performs further analysis from a Tier 1 spatial object in order to produce a Tier 2 spatial object, a route from one point to another. The tool uses the edge costs from the maneuver network as input for its route solvers. Given an origin and destination, it can solve for a "best" route using a single cost (such as cover and concealment or time) and multiple cost constraints, or a route based on the size of a unit's movement formation. Given an origin, the movement projection tool can solve for all available routes given a time or distance cost constraint. Below is a screenshot of a route which was calculated to be the fastest from the origin to the destination (Figure 5).

BTRA has uses that will enhance the processes and productivity of terrain analysis teams (currently attached to echelons of brigade and above), enable rapid planning and course of action analysis within command and control constructs, inject terrain and weather effects awareness into C2 systems, and present new capabilities for commanders, command staffs, and soldiers to leverage at battalion level and below. With respect to net-centric operations, BTRA is at the forefront in ensuring information dominance on the battlefield, fusing together information from different data sources in order to create products that are standardized and reusable across the force. This results in a more agile and proactive command and control framework, allowing commanders and their staff to direct their resources on strategy and countering enemy courses of action, rather than spending many man-hours collecting, aggregating, and deciphering raw data.

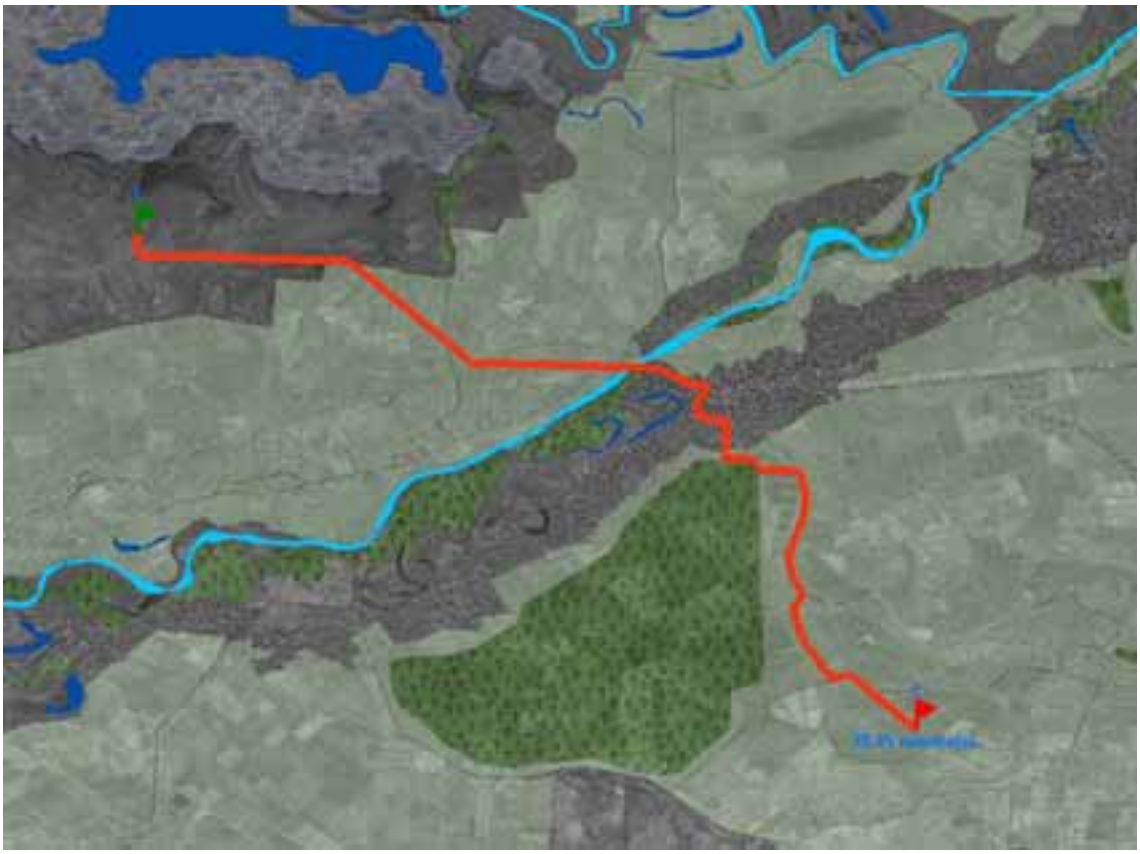

Figure 5: Screenshot of Fastest Route

The utility of BTRA software applications and their data products, the tactical spatial objects, in the military decision making process is abundantly clear. Since the spatial objects are grounded in military doctrine and linked to military tasks, they enable the commander to produce a comprehensive plan that has incorporated the effects of terrain and weather on equipment and weapons platforms. Currently, a commander and his staff generally rely on relatively low-fidelity maps and incoming weather forecasts to assess the impact of the battlefield environment on operations, already a time consuming process. High fidelity data sources and their associated complex analyses which could allow for better decision making and force deployment are even more time consuming to implement manually. With BTRA, however, the terrain analyst not only has access to high-fidelity data sources, but also the tools to turn the raw data into operationally relevant knowledge such as candidate battle positions, assembly areas, or routes, all linked to the commander's mission, timeline, and tasks. The commander along with his staff can then further refine these candidate tactical spatial objects based on the tentative plan and the current enemy situation or for different friendly or enemy courses of action.

This concept becomes more powerful when coupled with a grammar that defines a military order with semantic and syntactic consistency. In this case, tactical spatial objects can be reliably mapped to the unambiguous tasks specified in the order. When orders flow between echelons, links to necessary associated tactical spatial objects can generate requests for their computation and dissemination. These requests can be fulfilled by personnel or by an automated system, but the key is that there is less effort spent by both the terrain analyst team and the commander on what data products and processes are needed

to support the planning process, and more effort on refining the plan itself. This construct also lends itself for use in unmanned or simulation systems where a well-defined grammar and related spatial objects can specify the behavior of automated units.

2.4 geoBML Concept

The overarching construct within the Military Decision Making Process is that of Mission; Enemy; Terrain and Weather; Troops; Time; and Civil considerations (METT-TC). METT-TC both defines the variables of the battlefield, and also acts as a concept for organizing facts, data and information related to the mission at hand. In many cases the information used by the Warfighter to make specific decisions is an abstraction of many underlying facts and data from specific fields of endeavor (Warfighter Functions). This is particularly true in the case of information pertaining to realm of Terrain, which is supported by very complex Geographic Information Systems (GIS) and sets of terrain data.

In the past Warfighters made decisions using information gleaned locally from low fidelity sources such as maps, limited reconnaissance's, long range forecasts or generalized descriptions of terrain and cultural features. Current GIS systems now allow for the rapid development of significantly higher fidelity and more current, accurate and tailored technical products. The problem, however, is that many of these products in their raw form are very technical in nature and are not in 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. The Battlefield Terrain Reasoning and Analysis (BTRA) program and geoBML provide the conduit that will now put tailored, high fidelity knowledge in the hands of decision makers at all levels.

Underlying BTRA and geoBML is a concept of Tactical Spatial Objects (TSOs) that are arrayed in three tiers. TSOs are defined as:

- An object developed with topographic support systems/applications that directly support the planning and execution of tactical military operations.
- In addition to a geospatial component the TSO contains relationships to specific military operations, missions and tasks and may also have distinct relationships to various types and echelons of military organizations.

Tier 1 constitutes those TSOs 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 TSOs
- Maneuver Networks
- Mobility and Choke Point TSOs
- Fields of Fire and Dead Space TSOs

Tier 2 TSOs require significant METT-TC context. They represent candidate products that are associated with specific missions and tasks, by type unit and echelon. They will be complete with regards to geospatial information, but will not have a complete set of operational attributes, e.g. specific unit and time to execute, etc. Examples are:

- Indirect Fire Firing Positions
- Assembly Areas
- Battle Positions
- Engagement Areas

Tier 2 TSOs may take several forms in that the base product will be fairly geospatially dense (containing hundreds or thousands of vertices) yet may be abstracted to only a few points, or even displayed as a simple graphic along with appropriate metadata, while conveying the necessary operational information.

Tier 3 TSOs 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 TSOs and been further refined based upon METT-TC. They may also include graphic control measures and other items that are often associated with or influence the perception of terrain. They contain operational attributes, e.g. specific unit and time to execute, etc. and, most importantly they represent and convey a command decision.

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 TSOs. The Tier 1 products are then often used to compute Tier 2 products and refine them into Tier 3 products.

geoBML provides a means for the Warfighter to request TSOs and allows for these TSOs to be defined, described, stored (either as objects or representations of the objects) in the C2IEDM/JC3IEDM and made readily available to the diverse decision makers. As the development of geoBML progresses specific, highly defined TSOs will be associated with a large array of operational and tactical missions and tasks and ordered by type unit and echelon. Thus, when a unit initiates planning for a mission or contingency it will automatically query the supporting C2IEDM/JC3IEDM for the existence of the appropriate supporting TSOs as it selects various missions and task options during the Course of Action (COA) development process. If these products exist, they will be either contained or represented in the C2IEDM/JC3IEDM, and will be retrieved and immediately support the planning process. If they do not exist, the query will be forwarded to the supporting terrain and weather analysis support cell, which will produce and distribute them. Hence, BTRA and geoBML create a semantic and syntactic bridge between the highly specialized domain of terrain and weather reasoning and analysis and the immediate needs of the operational Warfighter.

The diagram below (Figure 6) indicates the relation of the various TSOs to the "cognitive hierarchy" discussed earlier. The left hand side indicates where the actual TSO will be stored.

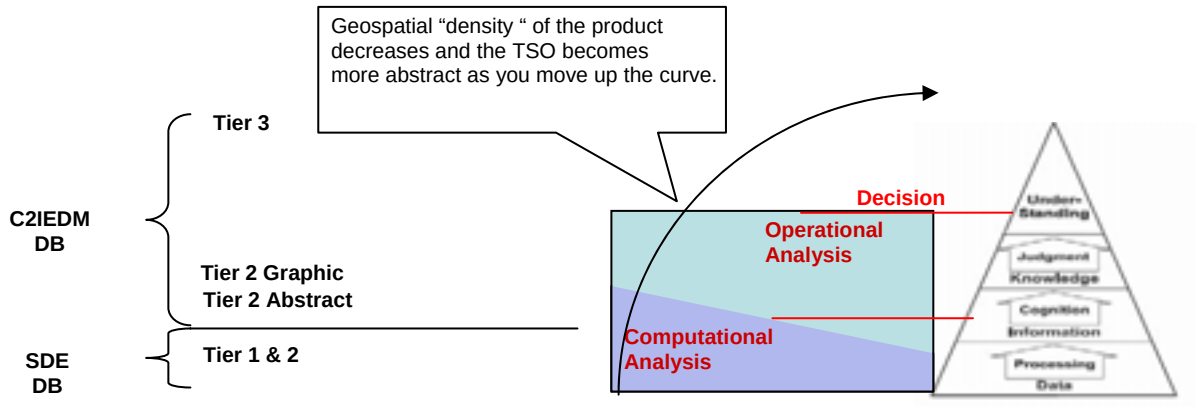

Figure 6: TSO Relationship to Cognitive Hierarchy

3. geoBML Implementation

3.1 Integration with BML/C2IEDM

3.1.1 BML Implementation in C2IEDM

The original prototype implementation of BML was demonstrated using a real-world Army scenario in 2003. The purpose of the initial prototype was to demonstrate the concept and feasibility of BML based on the Army's Joint Common Database (JCDB) as the underlying data model. Follow-on work expanded the BML concept from purely Army to more of a Joint and Coalition flavor while focusing on standards. As such the underlying data model was replaced with the Command and Control Information Exchange Data Model (C2IEDM) now being replaced by the next iteration, the Joint Consultation Command & Control Information Exchange Data Model (JC3IEDM). The goal here was to demonstrate the ability of the C2IEDM to handle simulation type date in the form of units, graphical control measures, and executable tasks. The C2IEDM is a robust data model with approximately two decades worth of development history. It is currently maintained by the Multilateral Interoperability Program (MIP) [10], which is a voluntary and independent organization that represents more than two dozen countries and headquarters organizations. The MIP is focused on deriving a common data architecture and data model for multi-national interoperability through consensus of these participating nations and actively manages the configuration of the data model.

The C2IEDM includes common vocabulary related to all domains of military operations, such as maneuver, fire support, air defense, engineering, civil military operations, and anti-terror special operations. It was designed based on the information exchange requirements for C2 systems that exist on the battlefield and therefore deals naturally with units, orders, missions, tasks, situational awareness data, etc. The C2IEDM consists of the five standard battlefield entities: organization, materiel, features, facilities and persons. All data and relationships are well documented and publicly available. The BML constructs were mapped into the C2IEDM tables and attributes. There were many cases where existing C2IEDM tables and attributes corresponded well to various BML concepts and were mapped directly. In other cases new relationships were required in order to accurately represent the meanings behind certain BML constructs. In some cases, however, the C2IEDM needed to be extended in order to capture the full extent of the BML concepts. The extensions included the additions of enumerated values (e.g., new task types), additions of new attributes to existing tables, and the addition all new tables and attributes. Further details regarding the mapping of the BML constructs to the C2IEDM including a description of the extensions can be found in [11].

3.1.2 TSO Design and Implementation

The first step to incorporation of the geoBML concepts into the C2IEDM was to develop the implementation design for the TSO products and incorporate them into the overall demonstration architecture, covered in section 3.2. The design was primarily based on a number of high definition documents (HDD) generated for certain Tier 1 and Tier 2 TSOs. These documents identify the characteristics of the TSO and how it is used within a military context. Identified also are the inputs and outputs to the process of generating the product. The output parameters were used as the starting point for identifying how to represent these elements within the C2IEDM. It was determined that there was enough of a distinction between Tier 1 and Tier 2/3 products that there would be separate designs for each. Tier 1 products are more abstract and cover a much bigger area than Tier 2/3 products and consist of a very large amount of data. This led to the conclusion that the C2IEDM representation of a Tier 1 product should consist of a reference to the actual data product to allow for retrieval and viewing, and meta-data that describes the product. This meta-data would include of certain types of information that could be used to

query for and distinguish these Tier 1 products from one another. Examples of this meta-data include the specific type of product, unique identifier, bounding box extent, date/time stamp of creation, and version number. For the Tier 1 TSO design, it was determined that a Tier 1 TSO would be represented by a set of attributes that included the TSO product reference and the common set of meta-data parameters identified.

Tier 2/3 products are more specific and involve a smaller area within the bounds of a Tier 1 product. They are more focused on certain aspects how the terrain and environment will influence the planning decisions. Upon detailed review of the Tier 2 HDDs, it was determined that the Tier 2/3 TSOs should be characterized by their output parameters along with certain additional meta-data identifying product type, date/time stamp of creation, and version. Some of these output parameters were found to be unique only among one or two Tier 2 products, but a number of other parameters were common to most or all. One issue that was pervasive during the design and implementation process and continues to be unresolved was whether or not to include all the actual data points for the Tier 2 products within the C2IEDM or only store a reference to the actual product along with the bounding box extent as was done for the Tier 1 products. Initially, it was assumed that the entire Tier 2 product including all the data points would be stored within the C2IEDM. As time passed, it became clear that even the Tier 2 TSOs could potentially contain a very large number of points and would probably be more efficiently stored within a geo-spatial database. The initial implementation of the Tier 2 products did use a reference to the actual Tier 2 product, however, as mentioned the final decision on how to handle this issue has not been resolved.

Several different approaches were considered for incorporating the notion of a TSO within the C2IEDM. The first approach considered was to create a new entity to represent a TSO and make it a subclass of OBJECT-ITEM. As such a TSO would be an object and have its own unique identify. However, after carefully reviewing the definition and attributes of the FEATURE entity, which is a sub-class of OBJECT-ITEM, a second approach was considered that would make the TSO a sub-class of FEATURE. The FEATURE entity encompasses meteorological, geographic, and control features. This approach would work as long as the TSO concept was unique enough to consider it a fourth type of feature. Following is the C2IEDM definition of the CONTROL-FEATURE entity:

> A nontangible FEATURE of military interest that is administratively specified, may be represented by a geometric figure, and is associated with the conduct of military operations

After carefully considering this definition within the context of evolving definition of a TSO, a third approach was considered where the CONTROL-FEATURE entity would be used as the basis for representing TSOs. Upon further evaluation of these three approaches to include consideration of the MIP business rules for use and extension of the C2IEDM, the third approach was selected as the CONTROL-FEATURE entity seemed to best capture the TSO concept among existing entities and because this fit well within the spirit of the MIP business rules.

There were numerous aspects of the TSOs that were not explicitly represented by the CONTROL-FEATURE entity. In these cases part of the design and implementation process was to determine how best to represent these parameters. Some were simply added as new attributes to the CONTROL-FEATURE entity. In the other cases, these parameters, such as location and associations to other TSO were represented through existing associations via OBJECT-ITEM-LOCATION and OBJECT-ITEM-ASSOCIATION entities. Finally in some cases several new entities were added to capture associations of TSOs to units, equipment, and activity-codes.

The initial set of Tier 1 products implemented for demonstration purposes included the Maneuver Network, Obstacles, Concealment, Observations and Fields of Fire, Mobility Corridor, Cross-Country Movement, and Chokepoints. The Tier 2 products implemented for the initial demonstration environment

included Battle Positions, Assembly Areas, Attack Positions, Attack by Fire Positions, Assault Positions, Indirect Fire Positions, and Engagement Areas.

3.2 Demonstration Architecture

In order to evolve and validate the geoBML concepts a demonstration environment was developed integrating a number of software components. The overall architecture for this environment is shown in Figure 7. The centerpiece or focal point of the environment is the C2IEDM database that has been augmented to include the BML and geoBML representations. The actual TSO raw data is stored in the ESRI Spatial Database Engine (SDE). The SDE provides an enterprise wide repository for spatial data.

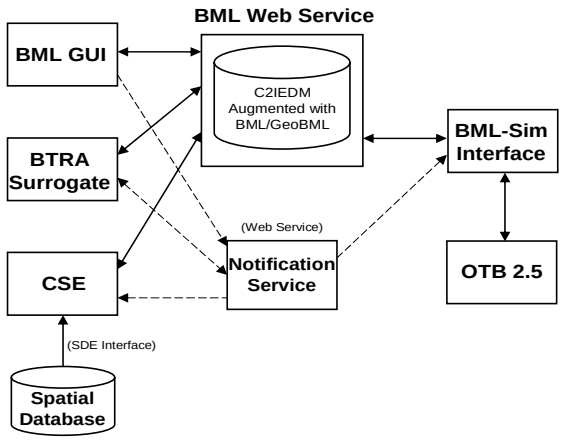

Figure 7: geoBML Demonstration Architecture

The BML/geoBML constructs are accessible via the BML Web Service component through a set of Java methods for accessing this information to include both inserting and extracting the data. The BML GUI provides the means to view the BML data in the form of an OPORD. In addition the BML GUI provides some limited access to view the geoBML data. The CSE is a prototype C2 planning application that provides the capability to develop one or more COAs through a graphically oriented interface to represent the units, control measures, and their tasks. It has been integrated within the geoBML environment via the BML Web Service and BTRA Surrogate Web Service to import and export BML orders, geoBML Tier 1 and Tier 2/3 TSO meta-data, and SA information. The CSE also interacts with the SDE to access the actual TSO products for display. The BTRA Surrogate application was developed as an initial representation of the capability to generate and store TSO meta-data within the C2IEDM. It reads pre-stored TSO Tier 1 and Tier 2 product meta-data from XML datafiles and inserts this information into the C2IEDM via the BML Web Service interface. The Notification Service is a separate Web Service implementing a publish-and-subscribe mechanism allowing notifications of certain events to be passed among the various components within this environment. Examples of how this service would be used include issuance of orders, request for generation of TSOs, and notification of the availability of TSO products.

The BML-Simulation application is the interface between the BML Web Service and the simulation environment. It includes the capability to retrieve a particular OPORD from the C2IEDM and forward it to the OTB simulation application. It also has the capability to monitor for friendly SA information generated by the simulation during execution and update the corresponding information within the C2IEDM.

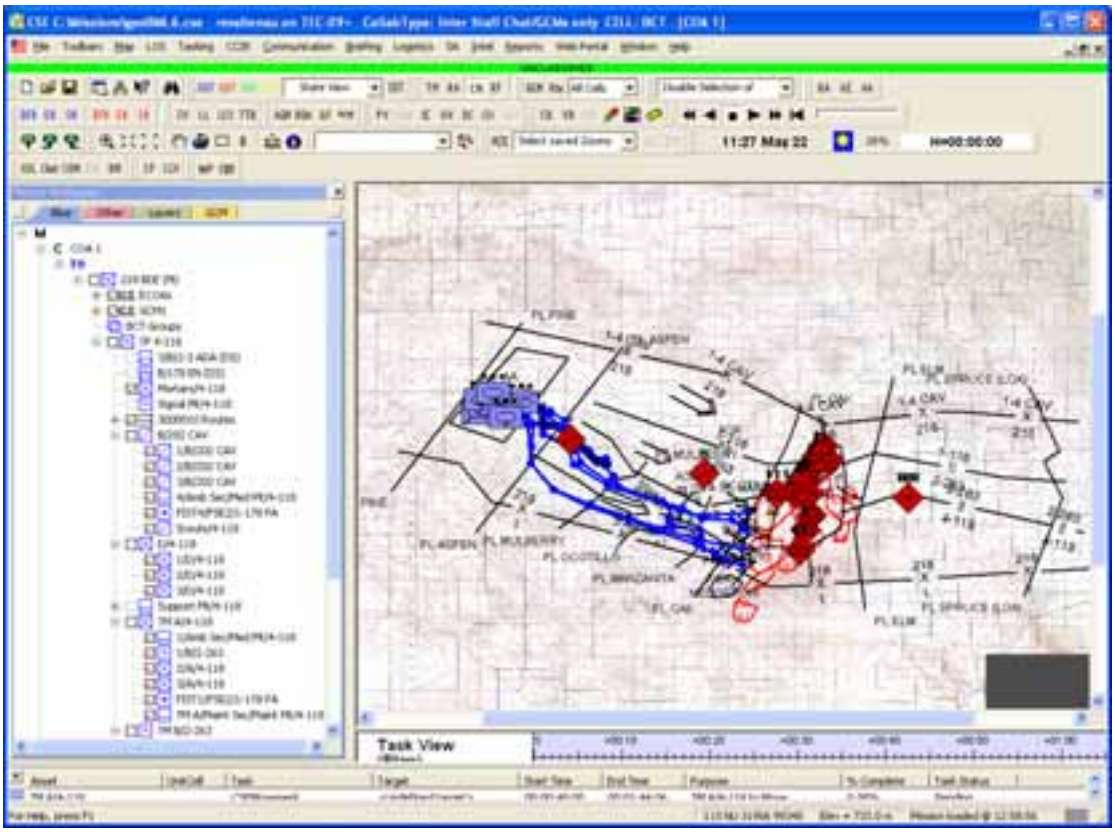

Figure 8: Example Mission in CSE

3.3 CSE Integration

3.3.1 Operational View

The Commander's Support Environment (CSE), a component of the Battle Command Support Environment (BCSE) developed under the Multi-Cell and Dismounted Command and Control (M&D C2) Program, was selected as a representative Command and Control (C2) system for the geoBML program.

The highly advanced BCSE supports cross-functional, collaborative mission planning and execution monitoring providing a Common Operating Picture (COP) for enhanced, real-time Situational Awareness (SA) in a net-enabled environment.

Whereas the BML GUI allows one to read a data formatted order (message), CSE provides the ability to visualize a data format geoBML order (Figure 8), conduct the MDMP analyzing multiple courses of action (COAs), and then produce a geoBML order. When a geoBML warning order (WARNO) is issued, the data elements that make up the message are stored in various tables within the C2IEDM database. The planner at the subordinate unit is notified, using the Notification service, that the WARNO is available and provided the information needed to recover it from the database. He then downloads the WARNO and can read it in the BML GUI and display it in CSE. As a minimum the WARNO at this point provides the current task organization and the area of interest or "playbox" that the unit will be operating in. From this information the planner can query the database from CSE for any Tier 1 TSOs that might be available for the area and/or request any Tier 1 TSOs be created. These Tier 1 TSOs will exist in the SDE with reference information stored in the C2IEDM that provides the information needed to access the TSO.

TSOs that are available can be displayed in CSE overlaid onto the map view and assist the planner with initial Intelligence Preparation of the Battlefield (IPB). When higher headquarters issues the operations order (OPORD) this also goes into the database with a notification sent to the subordinate. The planner accesses the OPORD and can read it in the BML GUI and graphically display it in CSE. He then uses CSE to conduct the COA development and analysis portions of the MDMP process. He can adjust his task organization, create control graphics, and assign tasks to subordinates. As he is conducting COA development, or any time during the process, the planner can request that Tier 2 TSOs be developed. For instance, if the planner decides he needs attack by fire (ABF) or support by fire (SBF) positions for a particular COA he can request that the BTRA services generate potential locations for these. In fact, since TSO types are linked with ARTEP tasks within the database, as the planner selects tasks for units to execute a listing of possible TSOs related to that task can be provided for his consideration. As these TSOs are generated they can be displayed in CSE as potential candidates for the COA with an evaluation of their goodness in relation to each other based on the characteristics associated with them (location in respect to objective, fields of fire, cover and concealment, access, etc.). The planner selects the candidate that he feels best suits his needs, taking all aspects of METT-TC into consideration and this candidate becomes associated to the COA/plan. When planning is complete and a COA has been selected the planner exports the COA back out to the C2IEDM where all the information is stored in the appropriate tables and are linked into a geoBML order. This order can now be accessed by the BML GUI and any portions requiring completion are filled out and then saved. The order is then ready for issue. In the case of our testing, the order is issued to OneSAF Test Bed (OTB). Issuing the order to OTB causes the simulation to be initialized with the friendly and enemy units, their locations, the graphic control measures and the tasks assigned to the units. The units then start executing their tasks in OTB as per their orders. As the simulation runs, information is provided by the simulation back to the C2IEDM updating unit locations. CSE uses this information from the C2IEDM to track the progress of the units on its display allowing CSE to provide execution monitoring as well as planning.

3.3.2 Implementation View

The CSE was enhanced to interface to the geoBML Web service to send and receive geoBML orders to/from the C2IEDM and to receive Tactical Spatial Objects (TSO) references and SA updates from the C2IEDM. An interface to the BTRA Surrogate was implemented to request generation of TSOs. A simple subscribe and publish mechanism was implemented for the C2IEDM to notify subscribers when a new geoBML order was issued. The CSE provided the capability to plan a mission using the geoBML orders and TSOs.

The CSE executes in the Microsoft Windows environment. It is primarily written in C++ and it is built on CJMTK (ESRI ArcGIS), TEC BTRA, the ViecoreFSD Decision Support System (VDSS), and the Davinci Toolkit. The ESRI ArcGIS provides components for retrieving TSOs from the SDE and rendering the TSOs. The VDSS architecture enables the quick addition of modules for communication between CSE and other systems.

A Java application (CSE BML Bridge) was implemented by ViecoreFSD to interface CSE with the BML Web service and BTRA Surrogate Web Service (in this perspective the CSE BML Bridge is a Web services client). A CSE Notification Consumer is implemented as a Web Service for the geoBML Notification Producer client. All Web services use the Apache Tomcat Web Server.

A Socket connection is used to establish a connection between CSE and the CSE BML Bridge. CSE has a built-in messaging mechanism for loading and updating mission data as part of its collaboration functionality. New messages can be quickly built by the CSE's message generator which generates C++ and Java code for CSE messages. The generated code provides message allocation, access methods,

serialization, and de-serialization. The translation between geoBML data representation and CSE data model was implemented using this existing messaging structure.

An interface was implemented by ACS which provides methods to connect to the BML Web Service and access objects in the C2IEDM. The CSE BML Bridge subscribes to the geoBML Notification Producer for OPORD notifications. When an order is issued the geoBML Notification Producer sends a notification to the CSE notification consumer. This Web service uses the Java Remote Method Invocation (RMI) to invoke the CSE BML Bridge application. The CSE BML Bridge application then retrieves the OPORD from the C2IEDM, translates it into a CSE message and sends the message to CSE. CSE then displays the order, see Figure 8.

When the CSE user requests TSOs, the CSE sends a message to the CSE BML Bridge. The CSE_BML Bridge interfaces with the BTRA Surrogate Web Service to create new TSOs. The BTRA Surrogate stores the meta data in the C2IEDM. The CSE BML Bridge retrieves the reference to the TSOs from the C2IEDM and sends a message to the CSE. The CSE uses these references to locate the TSO raw data stored in the SDE and loads the TSO.

The CSE can request the CSE_BML Bridge for Unit Situational Updates (SA). The CSE_BML Bridge will read the active units locations from the C2IEDM and send any location updates to the CSE

4. Interoperability with Simulations

4.1 Integration with OTB

As mentioned above, the simulation environment used for the GeoBML demonstration environment is OTB version 2.5. OTB is an interactive, high-resolution, entity-level simulation that represents combined arms tactical operations up to the battalion level and is designed to meet the needs from three domains: research, development and acquisition; advanced concepts and requirements; and training, exercise and military operations. It provides an extensive list of entities including fixed and rotary wing aircraft, ground vehicles, dismounted infantry, and additional special models such as howitzers, mortars, minefields, and environmental effects. Simulated entities can behave autonomously; that is, they can move, fire, sense, communicate, and react without operator intervention. OTB is capable of interfacing to simulation applications as well as other OTB systems via two external interfaces that include the Distributed Interactive Simulation (DIS) protocol and the High Level Architecture (HLA) interface. For the GeoBML project, the DIS 2.04 interface was used.

The interface to the GeoBML demonstration environment is accomplished through a middle-ware application known as the BML-Simulation Interface as shown in figure 2 above. This application consists of two external interfaces. First a Web Service interface is used to pull a particular OPORD from the C2IEDM. The BML-Simulation Interface also includes the capability to push unit location and status information to the C2IEDM based on data it has received from OTB. The second interface provides communication with OTB via either DIS or HLA. A custom set of C2 Type messages are used to send information to OTB based on the contents of the OPORD. Standard DIS/HLA constructs are used for interpreting SA type information generated by OTB. In order for OTB to understand the C2 type information coming from the BML-Simulation Interface a new C2Msg library was added to the baseline OTB software. This is a standard C-language library that is created and linked into OTB in the same manner as existing libraries. It uses the existing interface mechanisms for routing the DIS/HLA messages to it for processing. It interacts with a variety of other exiting OTB libraries via callback functions and public access functions so share information about the simulated entities and the virtual environment. The C2Msg library understands the contents of the C2 Type messages identified earlier in this paragraph and is

capable of creating entities, control measures, and assigning tasks based on the contents of these messages.

4.2 Integration of BTRA Maneuver Network

The Army Engineer Research and Development Center (ERDC) has ongoing research in the area of using common maneuver networks for embedded training, mission planning, and rehearsal. The basic concept is to allow Army simulation systems to make use of a ground maneuver network generated by BTRA products. At the present time, embedded training capabilities involving simulation and Battle Command systems do not share tactical maneuver networks. The result is generally an inconsistent view of the battle space between these systems which can lead to invalid decisions regarding maneuver of forces during training, planning, and execution of the mission. The objective of this work being to develop a common, consistent capability for assessing mobility and dynamic maneuver potential between BTRA products used for C2 planning systems and Army simulation applications.

Work on this effort involved modifications to OTB for incorporating the BTRA maneuver network into the local route planning process. A new OTB library, libmaneuvernet was developed and incorporated into the OTB baseline software. The purpose of this library is to make use of the BTRA maneuver network when generating routes to be used by OTB ground entities during movement. When turned on, this capability acts to override the existing internal route planning algorithms found in the standard OTB software distribution. The maneuver network can be exported as a BTRA product in the form of shape file. This shape file is then read in at runtime by the libmaneuvernet and used for generating routes. The libmaneuvernet is implemented using standard C++ code and consists of a set of C++ wrappers that make calls to the core route planning routines which are implemented in Java. In addition to incorporating the BTRA maneuver network into the route planning process, other modifications were made to OTB as part of this effort to allow the maneuver network itself to be displayed on the OTB plan view display (PVD) as an overlay. This allows the user to see all the individual route segments and intersection nodes of the entire maneuver network. When an actual route generated by libmaneuvernet is displayed, the user can see all the network segments that made up the route. For more information regarding this effort and capability, including the implementation details refer to [12].

4.3 Overcoming Misalignment of Terrain Data

During development and preparation of the initial GeoBML demonstration, a problem was discovered involving the movement of the friendly units in the OTB simulation environment. In several instances, the units in OTB could not move properly along the routes provided by the CSE application based on the maneuver network generated via BTRA. OTB includes two libraries that are primarily responsible the planning and controlling ground entity movement. The RouteMap library provides a generalized low-resolution planning capability used by units. It does so by creating an internal map that represents all the large terrain features found within the terrain database. The library includes a search routine that uses this map to determine a course through the terrain from a given start point to a given end point which avoids any large obstacles. The MoveMap library provides routines that support near-term navigation for these ground units. Higher level OTB libraries including RouteMap provide near-term goals and movement constraints as input to these routines. MoveMap then generates near-term plans to achieve these goals. In general a near term goal is to reach a given waypoint along a route. Among the micro-navigational routines implmented by the MoveMap library is obstacle avoidance, which is used as the primary discriminator in determining the best course to follow among many possible courses.

Within OTB, the overall course for ground unit movement is generated by the RouteMap library. The way points of this course are then used by the MoveMap library as the near term goals for navigating through

the terrain. The actual path of the vehicles is determined by the obstacle avoidance routine implemented for MoveMap. For the GeoBML demonstration, the movement problems encountered were a result of the misalignment of the obstacles found in the BTRA maneuver network and those found in the OTB terrain database. The routes generated by the CSE application were based on avoiding the terrain obstacles found in the BTRA maneuver network. When plotted on OTB, there were a number of these routes that ran directly through one or more obstacles found locally within the OTB terrain database in such a way that the navigation routines within the MoveMap library could not find a valid solution. The result was that the OTB vehicles would simply not move in these areas.

In order to overcome this problem, several new movement behaviors were created that do not account for certain obstacles. In OTB, there are a variety of possible obstacles that the movement behaviors could possibly consider. Obstacles include other entities, rivers, lakes, canopies, trees, tree lines, buildings, steep slopes, craters, ditches, wire, and rock drops. In general all the existing movement libraries do take into consideration all of these obstacles. For the GeoBML demonstration, new movement and attack libraries were added for individual ground vehicles, and platoon and company ground units. Each of the new libraries was modeled after an existing library used to control the behavior for either movement or to assault/attack enemy units. For all the new libraries, however, the code was modified to ignore all of the obstacles identified above with the exception of other entities. This modification allowed the ground units to now move freely through the terrain, following the assigned routes based on the BTRA generated maneuver network and ignoring the effects of any obstacles associated with the local terrain database.

5. Conclusion.

In this paper we have discussed how advances in technology need to be driven by and paired with equal advances in processes and operating concepts, with the primary focus being on the Warfighter. This needs to be accomplished on the basis of an informed design and structured development, supported by rapid prototyping and operational experimentation, thus reducing the reliance on "serendipity". Currently the US Army's Topographic Engineering Center is managing several other research programs, along with BTRA and geoBML; they include the Joint Geospatial Enterprise Services Science and Technology effort and the BTRA Battle Engine project. All of these programs are components of an integrated and focused capability that will facilitate the rapid introduction of technology into a Warfighters' C2 framework. This capability will provide major research and development support for achieving "an accelerated collaborative MDMP or dramatically new processes that facilitate decision-making in the distributed highly dynamic future operating environment" as called for in TRADOC Pamphlet 525-3-3 [3].

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