Development of a Ground Vehicle Maneuver Ontology to Support the Common Operational Picture

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To meet information needs of operational commanders, user-centric applications will combine Global Information Grid (GIG) data and services to create a Common Operational Picture (COP). The COP, a single identical display of relevant information shared by more than one command, will facilitate collaborative planning and situational awareness. Land warfare decision-makers are particularly interested in ground vehicle mobility characteristics of the battlespace. This paper describes both the Mobility-COP, from which warfighters can assess the ability of forces to maneuver effectively under multiple environmental and tactical conditions, and a formal ontology design to achieve the Mobility-COP in the future GIG net-centric architecture.

The Global Information Grid (GIG) [1] is emerging as the next-generation architecture for making military command, control, communications, computers, intelligence, surveillance and reconnaissance information available as discoverable and callable services to a spectrum of users, software agents, and software systems. To meet information needs of operational commanders, user-centric applications will compose GIG data and services to create a Common Operational Picture (COP), defined in Joint Publication (JP) 3-0 [2] as, "a single identical display of relevant information shared by more than one command." The COP will facilitate collaborative planning and situational awareness. The COP will be a user-tailorable selection, organization, and display of information obtained from diversely distributed data sources and services. Users across the force will have confidence the information provided in their respective COPs is drawn from consistent, trusted sources across the network.

Land warfare decision-makers are particularly interested in representation of ground mobility characteristics of the battlespace. Using these characteristics, warfighters assess the ability of forces to maneuver effectively under multiple environmental and tactical conditions. This portion of the COP is termed the Mobility-COP. Although a subset of the overall COP, the Mobility-COP presents a challenging mix of information provided by decision aids, environmental databases, platform performance data, doctrinal behaviors, and process simulation. These sources of data and services use a variety of data models that need to be reconciled through metadata and data mediation and then merged to create the Mobility-COP. This article describes the Mobility-COP and discusses development of an ontology to represent the data and information requirements of the Mobility-COP within the GIG architecture.

Mobility-Common Operational Picture

Assured Mobility

Assured mobility is a Force Operating Capability identified in the U.S. Army Training and Doctrine Command (TRADOC) Pamphlet 525-66 for future operational environment capabilities. It states the assured mobility framework:

> ... includes all those actions that guarantee the force commander the ability to deploy, move, and maneuver, by ground or vertical means, where and when desired, without interruption or delay, to achieve the intent. [3]

The assured mobility concept ties into the larger operational framework as an overarching enabler supported by the various battlespace functions, including Engineer Battlespace Functions of Combat Engineering (mobility, countermobility, and survivability), Geospatial Engineering, and General Engineering. Unification of data and information across the various battlefield operating systems (BOS) components requires unification of conceptual data models across software systems manipulating that information. Specifically, a common vocabulary and formalized semantics are needed to describe ground vehicle mobility data for software support to movement planning and mission monitoring. Design of the Mobility-COP ontology serves this purpose, identifying the common concepts relating ground vehicle mobility across the components in the operational framework for assured mobility.

The following are the four imperatives of assured mobility that are linked to the elements of combat power [4]:

1. Develop mobility input to the COP.
2. Establish and maintain operating areas.
3. Negate the influence of impediments on operating areas.
4. Maintain mobility and momentum.

The first assured mobility imperative, *develop mobility input to the COP*, serves as the impetus for defining the Mobility-COP. Armed with identified critical mobility elements for the COP, the commander will gain improved situational understanding through the use of geospatial tools that combine improved intelligence, surveillance, and reconnaissance capabilities with terrain data. Each of the four imperatives for assured mobility has implications for what mobility-related data and information are needed for the Mobility-COP. These concepts provide insights and serve as a guide for further analysis, organization, and scoping of the Mobility-COP.

More formally, the Mobility-COP is defined as a subset of the COP consisting of relevant movement and maneuver data and information shared by more than one command [5]. The Mobility-COP can be tailored for various users and includes data and information for mobility of individual combatants, ground vehicles, and autonomous/robotic vehicles. Interoperability across battle command systems and simulations for mission planning and embedded training cannot be achieved without effective sharing of data and computational services. Effective sharing implies

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the ability to express concepts that can be understood by diverse data sources and services.

With the requirement to enable interactions across multiple existing, emerging, and rapidly adapting systems, it is no longer possible to hard-code all systems to a single common data model. In contrast, given a common core data model, it is feasible for multiple systems to use adaptors and mediation services to express system-dependent concepts in the common interchange language. For this reason, development of a formal ontology for the Mobility-COP will provide a defined vocabulary and common semantics to serve as the basis for required interoperability. Following GIG guidelines, subsequent submission of the ontology to the Department of Defense (DoD) Metadata Registry and Clearinghouse[1] will make the model available to other domains.

Elements of the Mobility-COP Ontology

The Mobility-COP design team initially conducted a review and analysis of doctrine, data structures, standards and systems regarding ground vehicle mobility and maneuver. This analysis resulted in an initial slate of data categories and features/attributes for the Mobility-COP. Other data sources and standards which provided sub-elements or attributes to the above categories were examined; these included the data dictionary of the Force XXI Battle Command Brigade and Below, the OneSAF Objective System (OOS) Environmental Data Model (EDM), as well as Commercial Joint Mapping Tool Kit Battlespace Terrain Reasoning and Analysis (BTRA) products. A systems engineering-based process was conducted to obtain input from subject matter experts and stakeholders as a critical part of determining the elements and a hierarchical structure. The assured mobility imperatives discussed previously and the Army Universal Task List were used as part of the process. Analysis of the inputs from the participants resulted in eight top-level categories of information defined in Table 1.

Emerging concepts and capabilities of the GIG, as well as current and emerging standards and tools, were investigated to define what is meant by a Mobility-COP relative to data, specifications, and Web services. To the extent possible, the Mobility-COP will reuse applicable standards, tools, and products rather than developing these over again. It is also not the intent of this work to define or redefine geospatial features and attributes that are found in existing standards, or to manipulate or normalize them. Recent publications by Dobey and Eirich [6] and Miller and Birkel [7] discuss issues associated with geospatial data and its representation and source, vis-à-vis the GIG. Our current intent is to represent terrain features within the Mobility-COP using the OOS EDM based on the Environmental Data Coding Specification (EDCS). The work of Dobey, Eirich, and Loaiza, [8] relating to environmental extension to the Command and Control Information Exchange Data Model (C2IEDM), using the EDCS, is also relevant to Mobility-COP development. Other related ontologies currently under development include a synthetic environment representation [9] and a DoD core taxonomy [10].

Mobility-COP Ontology Development

Noy and McGuinness [11] describe the development of ontologies in a step-by-step process. The first step is to determine the domain and scope of the ontology. We used their process, combined with subsequent analysis, to develop a hierarchal structure based on the BOS combined with competency questions (which a knowledge base should help answer). Based on the U.S. Army Operations Order format, an initial list of competency questions was generated:

- Where are the obstacles to maneuver?
- What are effects of terrain and weather on friendly (or enemy) ground vehicle maneuver?
- Where are the friendly (or enemy) avenues of approach?
- Where is the key terrain for friendly (or enemy) maneuver (e.g. mobility choke points, bridges)?
- What are the effects of observation and fields of fire on maneuver?

These questions assume that the area of operations and the mission are known in terms of the five W's [12]: who, what, when, where, and why. This leads to the next step in the development of an ontology: the reuse of existing ontologies. The C2IEDM is an internationally accepted data model[2], and recent studies have investigated the development and sufficiency of the C2IEDM ontology [13]. Although the concepts of maneuver analysis and mobility are not well represented, it offers much of the context required for the Mobility-COP ontology.

Tolk and Blais [14] describe a taxonomy as *a tree structure of classifications for a given set of objects*, and an ontology as *an*

Table 1: *Mobility-COP Top-Level Categories*

Categories	Definitions
Terrain	The natural and manmade features and their attributes that may influence mobility or manuever of ground vehicles.
Obstacles	Those terrain features or other objects or conditions that disrupt or impede movement of ground vehicles.
Weather	Current and forecasted weather conditions that affect mobility and maneuver (visibility, precipitation).
Maneuver Analysis	The results of an analysis to ground vehicle movement relative to mission, command and control, local culture, and other considerations. Also includes information classes required for the analysis.
Route Planning	A route plan (directions for moving from A to B), the results of intermediate steps to obtain the plan and a subset of the required data.
Threat Analysis	The location, capabilities, and other information (potential actions) relating to threats to maneuver that can include, in addition to enemy forces, local populations, and cultural effects.
Forces	Information relating to manuever and transportation units, and individual platform locations and capabilities as related to mobility and maneuver.
Utilities	Information (metadata) that may be applicable to all elements of the Mobility-Common Operational Picture.

attempt to formulate an exhaustive and rigorous conceptual schema within a given domain. A key distinction is that an ontology is not limited to a tree structure, but can represent a multiple inheritance hierarchy. For example, the subclass Minefield may simultaneously be considered a member of the Obstacle class while also being a member of a terrain or facility class. It would inherit some properties from each superclass.

Table 1 presents the top-level components defined thus far. The following provide descriptions of those components as they pertain to ground vehicle mobility and maneuver analysis.

Terrain

The terrain component of the Mobility-COP data model is defined as the natural and man-made features and their attributes which may influence mobility or maneuver of ground vehicles. Terrain includes natural and man-made features, where man-made features include minefields, bridges, roads, etc. Man-made objects are *things on, in, or over the terrain* (such as roads, tunnels, and bridges, respectively) and need to be distinguished from the underlying physical terrain (ground and water). Due to the extensive past and present work in the area of terrain data modeling, numerous representations are readily available that meet portions of Mobility-COP requirements. These models have many complementary representations that can be mined for use in the Mobility-COP; however, they also possess conflicting representations that need to be resolved for use in the Mobility-COP.

Obstacles

Obstacles consist of those terrain features or other objects or conditions which disrupt or impede movement of ground vehicles. As with terrain, obstacles may be natural (cliff, ravine, swamp) or man-made (minefield, log barricade, rubble). Some Terrain objects, whether man-made or natural, can also belong to the Obstacles class based on characteristics that cause these objects to disrupt or impede movement of ground vehicles. With an automated reasoner[3], members of various classes can be automatically classified as obstacles based on their properties; for example, a river with certain width and depth values can be classified as an obstacle. If those property values change, say during a drought, then the river may cease to be an obstacle. Obstacles are also fully specified in existing data models (e.g., Table 2) and can be reused for Mobility-COP purposes.

Weather

Weather consists of current and forecasted weather conditions, which effect mobility and maneuver (visibility, precipitation). This component has a similar structure to Terrain in that it is best characterized as a geographic region having certain physical and temporal characteristics. There are numerous data representations that meet Mobility-COP information requirements.

Maneuver Analysis

Maneuver Analysis includes the results of analyses related to ground vehicle movement with respect to mission, command and control, local culture and other considerations. Some researchers have observed that efforts to reach common terrain and environment models have been focused at the data level rather than at the information or knowledge level. The distinction is important. Systems have primarily dealt directly with the raw data characterizing a geographic region, performing various processing to derive some battlefield effect (such as line-of-sight). Rather than having such information available directly, numerous systems spend processing resources to derive the higher-order effects and often compute those results over and over again. Moreover, the raw data are extremely large, making it very inefficient to distribute over a network. What most systems really require is not the raw data itself, but the derived products (e.g., a geometric line-of-sight envelope). In recognition of this fact, the U.S. Army Engineer Research and Development Center's Topographic Engineering Center is defining a data model for a Geospatial Battle Management Language that:

> ... seeks to abstract and represent terrain and dynamic environment through a rich set of discrete objects (spatial and temporal) and relationships to tactical entities and tasks. [15]

The effect will be to reduce large terrain data sets to their tactical essence and express the reduction in an ontology for interoperability at the conceptual level. This work has clear relevance to the Mobility-COP ontology design effort.

Route Planning

Route Planning contains the route plan (directions for moving from A to B), the results of intermediate steps to obtain this plan, and a subset of the required data. Derivation of the routes is dependent on information from the other

Table 2: *Attributes of the OneSAF Objective System Environmental Data Model Minefield Area Feature[4] (a region throughout which explosive mines have been laid)*

Attribute Name	Description[5]
CASE_BURIAL_FRACTION	The fraction of the case that is buried beneath the terrain.
COMPLETION_PERCENTAGE	The extent of completion in terms of fractional ascension from start of construction to completion of construction.
DURATION_OVERVIEW	The quantity of time in gross sense that the minefield may be assumed to be active.
EXPLOSIVE_MINE_TYPE	The type of explosive mines (e.g. anti-tank, anti-personnel).
FORCE_IDENTIFIER	A textual identifier of a military or civilian force (which created the minefield).
GENERAL_DAMAGE_FRACTION	The extent of damage to the minefield in terms of fractional degradation from a fully functional state.
MINE_ALLEGIANCE	The military allegiance of the force responsible for the creation or maintenance of the minefield.
MINE_DENSITY	The areal density of explosive mines within the minefield. Units of one mine per square meter.
MINEFIELD_MARKING_TYPE	Specifies by who and how the minefield is marked.
NUMERIC_OBJECT_IDENTIFIER	The numeric identifier.
PREPARED_EXPLOSIVE_DESTRUCTION_COMPLETION_FRACTION	The extent to which the minefield has been prepared for destruction by explosives in terms of fractional completion.
SOURCE	The source from which the data were captured or upgraded.
UNIVERSALLY_UNIQUE_ID	Universally unique identifier, guaranteed to be unique to a specific machine (computer) at a specific time.

Mobility-COP categories; for example, slope information from terrain, minefield placement and status from obstacles, precipitation and temperature from weather, or mission and own-force mobility assets from forces. The BTRA software is a current decision aid performing this type of processing to generate route plans. Because the routes are products of such processing, BTRA can become a software service providing input to the Mobility-COP in the GIG environment.

Threat Analysis

Threat analysis from the Mobility-COP point of view describes ways in which the adversary can potentially disrupt mobility and maneuver during the course of a mission. In general, these can include areas to be avoided (when safe routes are desired) or approached (when the mission is to attack). For example, a fast, safe route through an urban area may need to include (in route planning) not only information regarding historical improvised explosive device locations, but also local market events (time and location). The challenge is to be able to express not only known threats (the physical location of an enemy force), but also the probability that the force will attempt to disrupt a mission.

Forces

The Forces component describes information relating to maneuver and transportation units, and individual platform locations and capabilities as related to mobility and maneuver. Since the representation of military forces is a key element of Command, Control, Communications, Computers, and Intelligence and modeling and simulation (M&S) systems, there are numerous representations available for reuse in the Mobility-COP data model. Clearly applicable are the XML schema representations used in the Defense M&S Office Unit Order of Battle Data Access Tool and the Military Scenario Definition Language (MSDL). MSDL is used for scenario initialization and scenario archival storage in OOS and has recently transitioned to product development status in the standardization process of the Simulation Interoperability Standards Organization. Taxonomies of military forces are also available in the DoD Metadata Registry and Clearinghouse.

Utilities

Utilities refer to information (metadata) that is applicable to all elements of the Mobility-COP. Since the Mobility-COP will be a specialized collection of information and services from the distributed data environment rather than a specific physical data structure on the network, the individual components making up the Mobility-COP will be discoverable in their own right through adherence to the DoD Discovery Metadata Specification[1]. Furthermore, specification of Mobility-COP will include not only metadata descriptions of data products, but will also specify Web-based processes using standards adopted for use in the GIG such as the Web Services Description Language. Currently missing from identified GIG standards is emphasis on stronger semantics for data and service description and service composition through the use of semantic Web constructs such as the Web Ontology Language and the Web Ontology Language for Services. Full specification of the Mobility-COP will include such representations to solidify the foundation for enhanced interoperability.

Summary

The Mobility-COP ontology is a specification of those elements within the domain of ground vehicle mobility and maneuver analysis essential for military decision making, battle command and simulation. It provides a representation of ground vehicle mobility data within the tenets of the COP and the GIG.

To help achieve assured mobility for the Future Force in a net-centric environment, the ability to publish, access, process, and disseminate mobility and maneuver-related data, and information among battle command, modeling, and simulation systems is imperative. To accomplish this facet of interoperability, a data model and formal ontology are being developed. Eight high-level categories and respective sub-elements have been identified based on doctrinal review, needs analysis utilizing input from military subject matter experts, and functional decomposition of tasks relevant to assured mobility based on the Army Universal Task List. A significant component of the remaining work involves determining which elements are unique to the Mobility-COP ontology and which are available from existing or emerging ontology development. The results will be continuously vetted with the community and cross-checked with other existing ontology, data model, and standards development efforts.◆

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Disclaimer

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Notes

1. The DoD Metadata registry and the Metadata Specification can be found at: <http://diides.ncr.disa.mil/mdregHomePage/mdregHome.portal>.
2. The C2IEDM documentation is available at <http://www.mip-site.org/>.
3. Reasoner: Something that can find new facts from existing data (also known as reasoning) <http://en.wikipedia.org/wiki/Reasoner>. See <http://www.w3.org/2004/OWL/> for a list of available reasoners.
4. See the Environmental Data Coding Specification at <http://sedris.org> for exact definitions.
5. Area feature type (in this case a minefield) is a property of an areal primitive feature, other properties of the primitive feature contain the location and extent information (see <www.sedris.org/drm.htm>).

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