Toward Establishing the Mobility
Common Operational Picture: Needs
Analysis and Ontology Development in
Support of Interoperability
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ABSTRACT: The Army’s Assured Mobility concept calls for “establishing the mobility common operational picture” (Mobility COP) which includes assessing maneuverability in the battlespace. Moreover, the Global Information Grid (GIG) is emerging as the next-generation architecture for military command, control, communications, computers, intelligence, surveillance and reconnaissance information and will play a central role in composing the COP and the Mobility COP as a focus area of particular interest to land warfare decision makers. In the GIG, data and information will be made available through discoverable and callable services to the spectrum of users, software agents, and software systems. This implies there must be a means of interpreting data and information and a level of interoperability for exchanging and processing data and information. This furthermore necessitates that the elements of the Mobility COP be delineated and an underlying ontology be developed for common understanding and consistent application. To accomplish this, how does one determine what those elements are that comprise the Mobility COP? And, how can the input be organized into an ontology that promotes standards and interoperability among systems? This paper will describe the process we employed to elicit elements of the Mobility COP and to evolve a corresponding ontology. The scope of the work involves ground vehicle mobility at the tactical echelon.

1. Introduction

Assured mobility is a Force Operating Capability (FOC) identified in TRADOC Pamphlet 525-66 [1]. As stated there, 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.” The Army’s Assured Mobility concept calls for “establishing the mobility common operational picture” (M-COP) which includes assessing mobility and maneuverability in the battlespace.

The Global Information Grid (GIG) is emerging as the next-generation architecture for military command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) information. As such, it will play a central role in composing the COP in general and the M-COP in particular, the latter as a focus area of particular interest to land warfare decision makers. According to the Defense Acquisition Guidebook [2], the GIG is “the organizing and transforming construct for managing information technology (IT) throughout the Department [of Defense]. In the GIG, data and information will be made available through discoverable
and callable services to the spectrum of users, software agents, and software systems. These callable services should be semantically understandable and interoperable through interfaces that are sometimes unanticipated. This is a departure from the previous focus on standardized, predefined, point-to-point interfaces."

To achieve this net-centric data strategy, a means of interpreting data and information and a level of understanding and interoperability for exchanging and processing data and information are required. This furthermore necessitates that the elements of the M-COP be delineated and an underlying ontology for the M-COP be developed to promote common understanding and consistent application.

A previous paper described the characteristics of the M-COP and identified and discussed the development and operational requirements within the GIG architecture to generate and sustain the Mobility COP prior to and during military operations [3]. The present paper describes the process we employed to elicit elements of the Mobility COP and to evolve a corresponding ontology. The scope of the work involves ground vehicle mobility at the tactical echelon. We begin by describing a typical use case for the M-COP in a net-centric information environment.

2. M-COP Use Case

The following is a notional use case designed to demonstrate when the M-COP ontology could be used “in the field”. It begins with a tactical scout reconnaissance mission at the platoon level and moves into a simulation-based situation.

At 18MAR20060300Z, CPT Jones receives a mission from the squadron headquarters. His troop is to conduct a route reconnaissance from Al Baljaha to Frhaid in central Iraq. This route will be used on a convoy to move medical and communication supplies to a new forward operating base being established in Frhaid.

CPT Jones selects 1st platoon for this mission. They immediately begin their troop leading procedures in preparation for the mission. The platoon leader, 1LT Griffin, knows there are several things he must consider in both planning for the mission and while conducting the reconnaissance in order to provide the squadron with the necessary intelligence it needs and keeping his unit safe. Recalling from memory the things he will need to track from FM17-98, he writes down a list.

The platoon departs on time from Start Point (SP) Alpha. They move in a V formation with two sections overwatching the route while the headquarters section traverses the route collecting relevant data. Throughout the mission the teams note any terrain that would be adversely affected by inclement weather such as heavy rainfall.

Shortly after crossing the Line of Departure, Team C notes 30’ poles with wire (probably telephone lines) on both sides of the road. They are not continuous because of limited maintenance in this sector. Also, wires occasionally cross the road. These are both professionally installed and jury-rigged setups by locals. The Team leader notes the location of these as they may come in contact with vehicle antennae. Just past checkpoint (CP) 5, Team A observes a vehicle on the side of the road. They notify Teams C and B so they will be prepared to deal with it as they traverse the route. Initially they can only identify the object as a vehicle. Further investigation shows that it is completely off the road, but unoccupied. Sensing a potential improvised explosive device (IED), Team C notifies Squadron HQ and is told to bypass the vehicle and continue with the mission.

The route crosses the Farhawad River at CP 6. The Teams provide overwatch for each other as they cross the bridge noting the load capacity and general condition of the bridge. This includes any potential sabotage or natural degradation from exposure to vehicle traffic and weather. Also, the potential for the bridge to become washed out is an important issue they would identify. The teams also make a careful check for potential fording sites in the event the bridge is not available.

On the far side of the bridge, the platoon encounters a highway overpass. They check its height and condition. Additionally, Teams A and B scout out alternative routes for taller vehicles that can’t make it under the overpass. The majority of the road is concrete, but sections are worn away and consist of gravel or just dirt. Team C notes the location of extremely rough sections and areas that could potentially be used for refueling or unscheduled maintenance needs. They also note choke points along the route. These include areas that are possibly too narrow for larger vehicles to pass such as HETTs or armored vehicles. They check the shoulder of the road for ease of entry/exit. They would note steep drop-offs or extremely rough surfaces that would impede rapid transition to off-road travel.

They will also identify key terrain along the route such as high ground surrounding the route where an enemy could use to launch an attack or simply observe friendly movement along the route. Conversely, they will assess the fields of fire available to friendly troops that use the route as well as cover and concealment.

Nearing CP 8 which is a road intersection, they come upon another smaller road intersection. They believe this could be confusing to a convoy commander, especially at night. He may confuse this with CP 8 and turn too soon. They make careful note to mark this location as a potential navigation challenge. They would also be sure to send the updated map information through the appropriate
intelligence channels to get the new road added to overlays and future maps.

Near the end of the route, the road took the platoon around a small village. Like the river crossing, the teams provided overwatch for each other as they passed the village. They noted that there was some kind of festival going on in the center of town. Suddenly they heard the distinct sound of AK-47 fire and immediately trained their weapons in the direction of the sound. They watched carefully and realized that the celebration was a wedding party and the gunshots were simply shots in the air, common in this culture. They noted the incident for future reference.

Throughout the mission, the scout teams communicate with one another using tactical radio systems. They also maintain communication with their higher headquarters. Prior to departing, the unit signal officer advised them of potential “dead spots” for frequency modulation (FM) communications. They perform radio checks in these locations while conducting the reconnaissance to ensure convoys will be able to maintain communications while on the route. This may require retransmission stations be established to cover these dead spots.

Upon completing the route, the teams returned to their home base along the route. This trip went faster since they were already somewhat familiar with the route, but they did notice a culvert that ran under the road just outside the village that they had overlooked when the gunshots went off. They dismounted some scouts to take a careful look at the entrances to the culvert.

When the platoon returned to its home base, it conducted a thorough debriefing with the squadron S2, S3, and S4 officers. They relayed all that they had observed during the mission.

Although this reconnaissance was explained as an actual mission, it could just as easily been part of a simulation training mission. For instance, a unit preparing to deploy to Iraq may want to have its cavalry squadron rehearse route reconnaissance missions in a realistic training environment. This could readily be coded into a 3D driving simulator that permits the platoon leader to “drive” the route while transmitting information to a squadron HQ for it to begin its analysis of the data before sending it to a higher HQ. This would permit multiple echelons to train in as realistic of a scenario as possible. The information required for both the real-world mission would match that of the simulation mission. The M-COP will enable seamless transfer of the information between the real-world and the simulation by standardizing the data through a robust ontology of terminology relevant to ground mobility.

The ontology will provide a means to share all the information gathered during the reconnaissance mission as well as all the necessary mobility information that the scout platoon would require in order to perform that mission. The example of the vehicle on the side of the road provides several insights. The first is that a vehicle can be classified as a mode of transportation as well as an obstacle or even weapon system. In Somalia, junked cars were pushed into intersections and lit on fire to act as barricades. They are currently employed in Iraq as improvised explosive devices: remotely detonated or detonated by a suicide bomber. These “new” uses of the vehicle necessitate a method of describing one in general terms (2 wheel, 4 wheel, tracked, etc.) as well as specific purpose (obstacle, mode of transportation, etc.) so that all parties receiving information about the vehicle conceptualize the same thing. The M-COP ontology provides that tool by creating a class of obstacles. One instance of that class may be a truck that has been disabled or abandoned and currently is being used to block or slow traffic on a route. If the vehicle is a friendly vehicle that simply needs maintenance assistance, then it will also eventually become a mode of transportation. This requires the instance to have multiple parent classes. This is something that a standard hierarchy cannot accomplish, but the ontology can. Additionally, as new uses for the vehicle are identified, the ontology can be updated and modified to address all the new attributes and functions of the new vehicle type.

3. Eliciting Elements of the M-COP

3.1 Overview

This objective of this effort was to identify, expand, and refine the M-COP information requirements by eliciting input from the broader community of stakeholders in the use of the M-COP, and synthesizing this with data and information identified from doctrinal sources in preceding work. The M-COP team identified stakeholders with an interest, or a stake, in data and information representations associated with BC and M&S interoperability and assured mobility and set up a number of collaborative sessions to obtain their perspectives on M-COP requirements. Preliminary efforts to conduct these sessions were previously presented in [3].

3.2 Approach

The technical approach applied the problem definition phase of the Systems Engineering Management Process (SEMP), a robust, deliberate problem solving methodology taught in the Department of Systems Engineering at the United States Military Academy (USMA). It has been successfully utilized in a variety of applications, both military and commercial. The SEMP problem definition phase involves taking the original
problem statement and conducting a thorough analysis to focus and refine it as needed to ensure the right problem is being addressed and the desired end state is achieved. The results of the problem definition phase were system definition, corresponding functional decomposition, and identification of M-COP required information elements and hierarchical relationships.

### 3.3 System Definition and Context

The M-COP per se provides situational understanding with regard to ground vehicle mobility-related items for planning and executing (and decision making) in BC. The system under consideration with regard to establishing the M-COP can be defined as the Battlefield Operating System (BOS). The objective of this system, or system of systems, is ultimately to accomplish the mission. The system functions include: intelligence; maneuver; fire support; air defense; mobility, countermobility and survivability; combat service support; and command and control. The system subfunctions can be defined by the Army Universal Task List [4] (e.g., conduct route reconnaissance). These functions and subfunctions can be restated as M-COP ontology competency questions, which provide a means to scope the ontology. Competency questions are questions in the domain of interest that should be supported by the ontology [5]. Figure 3.3.1 below attempts to illustrate these relationships.

### 3.4 Stakeholder Identification

Stakeholders were categorized as client/sponsor, battle command, training, doctrine, analysis, acquisition, test and evaluation, and other communities. The initial list of stakeholders included several people/organizations with experience in military operations, battle command, training, and doctrine (e.g., representative from 3rd Infantry Division, and representatives from Army centers and schools). The team was able to identify and recruit stakeholders currently at the USMA and from across this spectrum by utilizing active duty military representatives with current (e.g., Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF)) experience as well as those with earlier battle command, training, and doctrinal experience. An added benefit of the experience of our stakeholder participants was that those involved in military operations over the last five years could bring aspects of evolving doctrine to light. The participants included academic faculty and staff and tactical officers for the Corps of Cadets.

The twenty-two stakeholders participating in the collaborative brainstorming sessions, in addition to M-COP project team members, covered the spectrum of stakeholder categories with the exception of test and evaluation. Customer/Sponsor and BC were deemed the highest priority categories and were well-represented. Conduct and inputs from the collaborative brainstorming sessions are discussed in the next section.

### 3.5 Stakeholder Collaborative Brainstorming Sessions

The brainstorming exercises were structured around a focus question found in documentation on the Provide Assured Mobility Force Operating Capabilities [6]: “What does the commander need to know to maneuver in the battlespace?” The team utilized Group Systems II software1 to facilitate the sessions. The software allows anonymous input via computer while permitting participants to see ideas or responses as they are submitted by others. This creates a dynamic sharing and accumulation of ideas and generally produces a large volume of information. Table 3.5.1 below provides a summary of the stakeholder participants. As future work, the team will attempt to review the results of these sessions with sponsors and via interviews with other stakeholder points of contact that did not participate in the collaborative brainstorming sessions to round out the assessment.

There were four hour-long exercises held on 23 September, 5 October, 18 October, and 10 November 2005. Each session addressed the question: “What does the commander need to know to maneuver or counter maneuver in the battlespace?” In addition, session 1 participants were asked to propose top-level categories for the elements of the M-COP data model. Based on the results of session 1; session 2 and 3 participants, who were from military operational backgrounds, provided comments on the proposed categories. Sessions 1 through 3 were conducted in-house at the USMA; session 4 was conducted via the web with participants in disparate geographic locations. The questions addressed by each session are given in Table 3.5.2 below.

Inputs from the participants were synthesized over the four sessions. The information was largely unedited, but attempts were made to spell-out acronyms and clarify input where necessary. Moreover, the input was loosely organized into categorized lists (input, sub-bullets, and comments) based on the responses received. The process for editing was conservative to preserve as much of the original information as possible; thus, redundant or duplicative information may be noted in the final content.

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3.6 System Functional Decomposition

Based on input received during the stakeholder collaborative brainstorming sessions pertaining use of the BOS to provide a good construct to group and assess M-COP data elements, the team embarked on a functional decomposition of the BOS. The functional decomposition was facilitated by the AUTL as described [4]. This reference provides a catalogue of the Army’s collective tactical-level tasks in a hierarchical fashion with doctrinal references. The tactical-level tasks are broken out by BOS, thus providing the essence of the functional decomposition.

The process included performing an exhaustive review of AUTL tasks and subtasks to identify those deemed pertinent to ground vehicle mobility-related information for planning, executing, and decision making in battle command, and for reviewing the associated measures of performance as detailed in [4]. Not all tasks in the AUTL have the same level of hierarchical detail for subtasks. Part of the effort entailed determining how far to decompose the tasks and where parent tasks would suffice for the project’s purposes. The following five Army Tactical Tasks of the seven BOS were identified as including functions, or tasks, pertaining to the M-COP:

- ART 1.0 Intelligence
- ART 2.0 Maneuver
- ART 5.0 Mobility/Countermobility/Survivability
- ART 6.0 Combat Service Support
- ART 7.0 Command and Control

This is not to say that the Fire Support and Air Defense BOS do not relate to the M-COP; rather, it was believed their specific mobility-related tasks and subtasks were sufficiently covered in the other BOS. Each of the selected BOS was systematically reviewed for tasks and subtasks deemed relevant to the M-COP. As stated previously, these were thought of as competency questions for the M-COP ontology. Figures 3.6.1 and 3.6.2 below depict the resulting functional decomposition for the identified tasks and subtasks as taken from [4].

The description and measures of performance associated with the tasks and subtasks provided a foundation by which to map the list of M-COP elements generated by the brainstorming and doctrinal review. This in turn facilitates the process of grouping the information into broader categories of terms and concepts to support the future development of class hierarchies for the ontology development.

Figure 3.3.1. System functional decomposition and relationship to competency questions.
Table 3.5.1. Stakeholder participant profile for collaborative brainstorming sessions.

<table>
<thead>
<tr>
<th>Rank</th>
<th>MOI</th>
<th>Unit / Cmd / Theater</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCO</td>
<td>ENGINEER</td>
<td></td>
</tr>
<tr>
<td>CPT</td>
<td>ENGINEER (2)</td>
<td>CO CDR Iraq, Afghanistan</td>
</tr>
<tr>
<td></td>
<td>INFANTRY (3)</td>
<td>3rd ACR Iraq, Mech Rifle CDR, HHC CDR Iraq, attached to 3ID Iraq</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mech IN CO CDR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1AD Iraq, Kosovo, Korea</td>
</tr>
<tr>
<td>MAJ</td>
<td>EN 2xAR MI EN IN ADA</td>
<td>2x OIF CO CDR, 2x OIF Battery CDR</td>
</tr>
<tr>
<td>LTC</td>
<td>IN FA</td>
<td>Haiti</td>
</tr>
</tbody>
</table>

Stakeholder Participant Civilian Experience

<table>
<thead>
<tr>
<th>Organizations</th>
<th>Stakeholder Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERDC</td>
<td></td>
</tr>
<tr>
<td>Alion/DMSO/SIMCI OIPT</td>
<td></td>
</tr>
<tr>
<td>USMA Staff and USCC</td>
<td>PEO STRI/FCS</td>
</tr>
</tbody>
</table>

Stakeholder Categories

<table>
<thead>
<tr>
<th>Battle Command</th>
<th>Acquisition, Analysis, Doctrine, Training</th>
<th>Customer/Sponsor, Policy, Analysis</th>
<th>Acquisition</th>
</tr>
</thead>
</table>

Table 3.5.2. Questions by stakeholder session.

<table>
<thead>
<tr>
<th>Stakeholder Exercise</th>
<th>Session Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideation regarding Commander's Needs for Maneuver</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td>Ideation regarding Categories to Bin M-COP Elements</td>
<td>1</td>
</tr>
<tr>
<td>Comments on Utilizing Proposed Categories to Bin M-COP Elements</td>
<td>2</td>
</tr>
<tr>
<td>Comments on Utilizing OPORD Structure to Bin M-COP Elements</td>
<td>3</td>
</tr>
</tbody>
</table>
Figure 3.6.1. Functional decomposition of BOS tasks.
3.7 Mapping

Given the lists of stakeholder input and doctrinal review results for potential elements of the M-COP and the functional decomposition of the BOS tasks, the next step involved mapping the potential elements into the relevant tasks or subtasks. For example, consider the Intelligence BOS subtask ART 1.3.3.4 Conduct Route Reconnaissance. A corresponding competency question is: “What ground vehicle mobility-related data and information is required to conduct a route reconnaissance?” As stated in FM 7-15 [4], the intent of a route reconnaissance for this subtask is to provide updated information about the conditions and activities along a specific line of communication. Freedom of maneuver and time to complete the task are noted as measures of performance for this subtask.
Items found in the potential M-COP elements list were reviewed and associated with the subtasks. Data elements that should be collected include road conditions, areas of cover and concealment, enemy activity, obstacles, line of sight, and so on. Figure 3.7.1 below provides a conceptual overview of the process. Note that this is not a one-to-one mapping; elements can map to several functions or subfunctions and often did.

Figure 3.7.1. Conceptual mapping of potential M-COP elements to mobility-related battlefield functions.

This deliberate methodology proved to be helpful in determining whether the breadth of conditions had been addressed. Considering each of the functions, subtasks or competency questions provided a means to review items that were garnered from stakeholders and from literature as well as a means to determine where elements were missing. It is important to note, however, that the team recognizes there is no one definitive “answer” regarding the list of M-COP elements or their categorization. The goal is not to provide a “perfect” data model but to provide an actionable model that captures the majority of the identified ground vehicle mobility information requirements and provides a solid basis for evolution of the data model over time as battlespace conditions and situations change.

3.8 Resulting Categorizations

After associating M-COP elements with functional tasks and subtasks across the BOS, the next step involved determining groupings of items into broader categories to support the data model development and future ontology formalization. After repeating the exercise for several subtasks, certain categories began to emerge. Again, the team recognizes there is not one definitive means to categorize the elements and will vet this through the broader community. An example of the mapping of M-COP elements to AUTL subtasks and the subsequent categorization is provided in Figure 3.8.1 (note: the numbering of items in the diagram relate to specific entries in specific stakeholder brainstorming sessions and are not critical to an understanding of the content of the figure). Based on this analysis and team discussions, principal categories of M-COP information were identified and are listed in Table 3.8.1.

4. M-COP Common Data Model Design

4.1 Overview

In progressing toward an actionable ontology for M-COP, the team proceeded to define an information model of ground vehicle mobility data needed to support maneuver planning and plan execution monitoring. That is, the intent was to describe the structure and semantics of the required information in the form of an application-independent conceptual schema. Follow-on refinement and further formalization of the data model will lead to development of a logical data model providing an application-independent description of the M-COP, and will provide an example external schema suitable for use by developers to create internal schema for applications storing and using the data. The focus on application-independence derives from recognition that there is no single correct way to organize the data identified in the stakeholder analysis. Rather, the logical data model provides an information structure that can be employed in various ways by various applications, and would generally be optimized (in terms of storage, processing time, etc.) in a physical data model (specified by an internal schema) for a particular use.

4.2 Approach

There are a number of data modeling techniques providing different levels of detail and specificity. One way to view the “semantics landscape” is shown in the “Ontology Spectrum” in Figure 4.2.1 [7]. The diagram shows representations of weak semantics at the lower left and progressive stages towards definition of strong semantics at the upper right. The figure also shows the techniques and standards used to represent semantics at various levels of the spectrum. It is important to note that different modeling and description techniques have different levels of expressiveness, and are therefore suited to different purposes. In working toward a conceptual model of M-COP, the project team is working its way up the spectrum toward semantic interoperability by starting with the controlled vocabulary and taxonomy levels generated through the stakeholders’ analysis and progressively adding refinements through stronger formalizations.
Figure 3.8.1. Example M-COP element mapping to AUTL tasks and top-level information categories.

Table 3.8.1. M-COP top-level categories.

<table>
<thead>
<tr>
<th>Categories from Functional Decomposition</th>
<th>Mapping to Initially Proposed Categories</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrain</td>
<td>Drainage and Relief Roads and Railroads Vegetation and Off-road terrain Installations</td>
<td>The natural and manmade features and their attributes which may influence mobility or maneuver of ground vehicles.</td>
</tr>
<tr>
<td>Obstacles</td>
<td>Obstacles</td>
<td>Those terrain features or other objects or conditions which disrupt or impede movement of ground vehicles.</td>
</tr>
<tr>
<td>Weather</td>
<td></td>
<td>Current and forecasted weather conditions which effect mobility and maneuver (visibility, precipitation).</td>
</tr>
<tr>
<td>Maneuver Analysis</td>
<td>Key Terrain Control Measures</td>
<td>The results of an analysis related to ground vehicle movement relative to mission, command and control, local culture and other considerations. Also includes some information classes required for the analysis.</td>
</tr>
<tr>
<td>Route Planning</td>
<td>BTRA products</td>
<td>A route plan (directions for moving from A to B), the results of intermediate steps to obtain this plan and some of the required data.</td>
</tr>
<tr>
<td>Threat Analysis</td>
<td>Stability and Support</td>
<td>The locations, capabilities, and other information (potential</td>
</tr>
</tbody>
</table>
A common definition for ontology is a “formal, explicit specification of a shared conceptualization” [8]. That is, an ontology provides a formalized vocabulary of terms and relationships among those terms used and understood within a domain, a “shared and common understanding of a domain that can be communicated between people and heterogeneous and widely spread application systems” [9]. In [10], the authors give the following reasons for developing an ontology (direct quotes from the source are shown in italics):

- To share common understanding of the structure of information among people or software agents

- To enable reuse of domain knowledge (within and across domains)

- To make domain assumptions explicit (encoding human interpretation of the information into the description of the information itself to promote common understanding by human and software agents)

- To separate domain knowledge from the operational knowledge (separating “what” the information entails from “how” the information is used)

- To analyze domain knowledge (starting from a clear description of current understanding of the information)
Clearly, “data models” do not fall into a single category along the spectrum. In fact, the distinction between “data model” and “ontology” in the literature is not clear. In [11], the author surveys a number of references and concludes that “all models classifiable on the ontology spectrum can be considered ontologies to a degree; however models with stronger semantics are more accurately classified as ontologies in the generally accepted sense than those with weaker semantics.” The immediate goal of the M-COP work is the description of a data model to the level of a meaningful classification scheme (“Taxonomy” in Figure 4.2.1). Refinements to the model in subsequent phases of the project are expected to apply stronger formalizations to provide more detailed semantics that will ultimately move the M-COP model into the realm of “Logical Theory” on the spectrum. This will be accomplished through the identification and formalization of interrelationships across the classes of data making up the M-COP as well as formal constraints on class properties and application rules, using standards such as the Resource Description Framework (RDF) and the Web Ontology Language (OWL).

Results of the stakeholders’ analysis provided identification of key concepts and gave us a list of applicable concepts at the lowest level in the ontology spectrum (controlled vocabulary). The M-COP team then applied their expertise to begin organizing the concepts according to different views of the data; e.g., using a functional break-out based on the Army Universal Task List (AUTL) as shown in Figures 3.6.1 and 3.6.2. The idea was to help the analysts identify the categories of M-COP information needed to support various tasks dependent on ground vehicle mobility. This follows a recommendation from [12] to survey tables of contents from domain relevant publications as a possible source for domain taxonomies. The upper layers of the structure shown in Figures 3.6.1 and 3.6.2 actually form a taxonomy of Army tasks relevant to ground maneuver. There is a clear classification scheme at those levels. For example, ART 2.0 Conduct Maneuver is subclassified as ART 2.2 Conduct Tactical Maneuver, ART 2.3 Conduct Tactical Troop Movements, and ART 2.5 Occupy an Area. While a useful organizing approach for associating the required information with the tasks, the subclassification scheme breaks down at the lowest level. For example, ART 2.2.10 Navigate from One Point to Another cannot be subclassified as “distance between points” or elevation. Instead, there is a different kind of relationship between the concepts at this level; one that could be called requires as in “ART 2.2.10 Navigation from One Point to Another requires a route analysis.” This relationship has a natural inverse, isRequiredBy, so that “distance between points isRequiredBy ART 2.2.10 Navigate from One Point to Another” is a natural consequence of the requires relationship. The further categorization of M-COP information shown in Figure 3.8.1 and summarized in Table 3.8.1 provides a basis for more careful definition of a taxonomy for M-COP data.

Definition of the relationships among concepts and categories of concepts provides additional semantic content to the information model, moving up the ontology spectrum to notions of Relational Model, Entity-Relation (ER) Model, Unified Modeling Language (UML), and even to the beginnings of logical theory specifications, in accordance with the degree of formality and specificity used in the formalization of the information model. The current target of team activities is definition of semantics to the level of Taxonomy so that a thorough identification and classification of ground vehicle mobility data is obtained as a basis for refinement through stronger semantics in the remaining portion of the project. Although not a target of this phase, prominent slots (or attributes) such as requires above are identified as they are revealed through the analysis of the data and data structures. Follow-on data model refinement will include application of technologies promoted by the Semantic Web community, e.g., RDF and OWL, to push information modeling to higher levels of semantic representation so that software can perform automated reasoning on the data.

While the Ontology Spectrum in Figure 4.2.1 can be seen as a guide for adding stronger semantics to a data model, a complementary approach to development of an information model is outlined in [10]. The approach involves seven steps and some additional guidelines and tests for grooming a nascent ontology.

### 4.3 Model Description

Each of the major M-COP information categories defined above is briefly discussed below to provide further insight into the nature of the data and the design of an ontology, including identification of related data models to be considered for re-use. It is again important at this point to remind the reader that the M-COP data model is an abstraction in the sense that it is not a single data base containing the identified categories of data (e.g., as tables in a relational data base), but where the actual data values are widely distributed across diverse systems and associated data bases. Those systems have physical realizations. The “physical realization” of M-COP is the development of
software applications that can find and gather ground vehicle mobility data needed to support maneuver planning and plan execution monitoring based on the M-COP data and services specification.

Identification of data models across the C4I and M&S communities that are relevant to the M-COP information categories serves two purposes: (1) it identifies both the logical and physical schema of available data from those actual systems and data bases, and (2) it identifies potential sources of “live” data when applications are developed in accordance with the M-COP specification. This is why we are promoting development of a formal ontology as the ultimate product of the project – the formal ontology becomes the information specification that can be read and understood by C4I and M&S software applications.

4.3.1 Terrain

The Terrain component of the M-COP data model 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). The latter can be abstracted as a geographic region having features and attributes at various postings (e.g., elevation, vegetation, soil characteristics). The man-made objects are also geometric in that they possess three-dimensional shapes but are located relative to the physical terrain region.

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 M-COP use; however, they also possess conflicting representations that need to be resolved for use in the M-COP. This work is ongoing. Moreover, a common mediation format is needed for more efficient design of data interchange across multiple systems [13]. A Visual Object Taxonomy (VOT) has been developed that provides “a detailed categorization of cultural and natural objects” [14]. This work strives to achieve distinct, mutually exclusive, unambiguous, and explicitly defined categories “formulated in a single language” (i.e., Webster’s version of the English language). Of particular interest to the C4I and M&S communities, the taxonomy was developed with attention to the well-established (and heavily vetted) Synthetic Environment Data Representation and Interchange Specification (SEDRIS) Environment Data Coding Standard (EDCS), Feature and Attribute Coding Catalog (FACC), and the Digital Feature Analysis Data (DFAD). The VOT is a ready-made structure for a major portion of the M-COP data model. The main aspect lacking from the VOT is explicit characterization of the relationship between the taxonomy categories and ground vehicle mobility (e.g., what characteristics make objects such as a Road effective for ground vehicle mobility while objects such as Rubble do not?). This is an area of further work for the M-COP team.

4.3.2 Obstacles

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 ground vehicle movement. Even another vehicle can be an obstacle to ground vehicle mobility under certain circumstances. With an automated reasoner, members of various classes can be automatically classified as obstacles based on their properties: for example, a river with certain width, depth, and current property 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. Creating a lane through a minefield does not eliminate the minefield, but may cause it to no longer be an obstacle. The ability of software to perform these inferences based solely on the abstract description of the data model, rather than hard-coded in software specialized for the application, is one of the merits of a formalized ontology at the Logical Theory level of the ontology spectrum. Obstacles are also fully specified in existing data models that are being assessed for re-use in the M-COP.

4.3.3 Weather

Weather consists of current and forecasted weather conditions which effect mobility and maneuver (visibility, precipitation). Weather has a similar abstract structure as Terrain, in that it is best characterized as a geographic region having certain physical and temporal characteristics. Existing Environmental Data Models (EDMs) provide detailed

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data representations that can meet M-COP information requirements.

4.3.4 Maneuver Analysis

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 [15]. 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 derived information directly available, numerous systems spend processing resources to derive the higher order effects, and often computing those results over and over again. Moreover, the raw data is 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. In recognition of this fact, a parallel and complementary effort (to M-COP) is being started in the ERDC Topographic Engineering Center (TEC) to define a data model for a Geospatial Battle Management Language (GeoBML). As described in [15]³:

“ERDC 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. Instances of these objects and relationships can then be extracted from the current and future large terrain and dynamic environment datasets and databases – essentially reducing large terrain data sets to their tactical essence and expressing the reduction in an ontology for interoperability at the conceptual level.”

Several of these terrain “products” were identified in the stakeholders’ analysis (avenues of approach, no-go areas, etc.). These are not features of the terrain per se, but representations of the effects of the terrain on ground vehicle mobility. Clearly, emerging ontology development for the GeoBML effort is of direct consequence to the Maneuver Analysis category of the M-COP data model.

4.3.5 Route Planning

Derivation of routes is dependent on information from several M-COP categories; for example, slope information from Terrain, minefield placement and status from Obstacles, precipitation and temperature from Weather, positions of advantage from Maneuver Analysis, presence and capabilities of enemy forces from Threat Analysis, and mission and own-force mobility assets from Forces. The Battlefield Terrain Reasoning and Awareness software [16] is a current decision aid performing such processing to generate route plans, so there is a clear opportunity for identification of software services within the distributed GIG environment. Specification of the M-COP in this regard will include not only representation of the products, but also characterization of the processes by which those products are obtained. This leads the M-COP specification effort toward another area of formalization, so-called Semantic Web Services, to provide stronger semantics for discovering and orchestrating Web services in the GIG environment [17].

4.3.6 Threat Analysis

One approach to refinement of the model for the Threat Analysis category is to perform a failure analysis; that is, what actions can other forces (military or non-military) take that undermine conditions that must hold in order for the movement plan to be successful. While an enemy cannot influence the weather to create poor road conditions, he can possibly attack a dam that would flood an area and have the same effect. Or, if the movement is highly dependent on fuel reserves, an insurgent IED attack on the fuel transport could create a condition for mission failure. The challenge for the ontology design is to be able to express these often intertwined cause-effect relationships matching enemy capabilities to create certain effects to underlying conditions or assumptions that must hold to achieve mission success. This is an area where the M-COP work can complement Battle Management Language ontology development work dealing with expression of plans and orders [15].

It has not yet been possible to survey the Intelligence community to determine data modeling formalisms that may already be developed. The M-COP team will investigate this domain in the next phase of the development.

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³ The Coalition Battle Management Language (C-BML) Study Group Final Report included contributions from a number of researchers in the C4I and M&S communities. The particular contribution relating to a GeoBML was submitted by Mr. Mike Powers of the ERDC Topographic Engineering Center.
4.3.7 Forces

Since the representation of military forces is a key element of C4I and M&S systems, there are numerous capabilities available for reuse in the M-COP data model. Clearly applicable are the XML Schema representation produced by the Unit Order of Battle Data Access Tool (UOB DAT) [18] and the XML Schema formalization of scenario data, including forces, in the Military Scenario Definition Language (MSDL) [19, 20]. MSDL is currently undergoing international standardization through the Simulation Interoperability Standards Organization (SISO) and is being used for scenario initialization and scenario archival storage in the OneSAF Objective System. Taxonomies of military forces are also available in the DoD Metadata Registry and Clearinghouse. Early efforts to create more formal ontologies for military unit behaviors are described in [21] and for other military M&S purposes in [22]. Refinement of the M-COP data model will leverage these prior efforts as appropriate to M-COP information scope.

4.3.8 Utilities

In addition to spatial characteristics, M-COP data categories also have temporal characteristics. Examples include:

- Terrain: An obscurant or contaminated area that disperses over time or a physical feature such as a river bed that can be dry or flooded under certain conditions at different times of the year.
- Obstacles: A minefield may be an obstacle at one point in time but no longer an obstacle when a lane has been cleared through the minefield.
- Weather: Planning needs to be concerned with current and near-term weather conditions, as well as forecasted conditions at some future period of time in some particular geographic region.
- Maneuver Analysis: Conditions of interest for a mission in 24 hours can be considerably different than for a mission occurring in 72 hours.
- Route Planning: Routes planned under current conditions can be considerably different than routes planned under forecasted conditions.
- Threat Analysis: Threat conditions change over time as the enemy maneuvers or is attrited. Threat analysis has to deal with current perception as well as projected threat disposition.
- Forces: The ground vehicle mobility capabilities of the forces change as vehicles suffer battle and non-battle losses and as fuel supplies are expended. The future composition of a force can depend on forecasted threat and weather.

The Utilities component will relate the categories to common spatial/temporal characteristics. Other common constraints and formalizations that are identified in follow-on development work will be addressed in this information category.

Since M-COP is really more of a specialized collection of information and services from the distributed data environment (i.e., it can be thought of as a virtual distributed database on the GIG) rather than a specific physical data structure on the network, the individual components making up the M-COP will be discoverable in their own right through adherence to the DoD Discovery Metadata Specification (DDMS) [23]. Therefore, the metadata associated with M-COP information components must at a minimum adhere to the DDMS. As the M-COP data model refinement work continues from this point, additional metadata that is not identified in the DDMS that is considered essential to the M-COP will be identified and be considered as recommendations to that standard if it is deemed beneficial to the community at large to do so. Such recommendations will be coordinated with the GIG M&S and C2 COIs as appropriate to ensure agreement with similar metadata identification activities.

5. Services Related to the M-COP

The previous discussion has focused on the data modeling side of the M-COP. Equally important in the GIG environment are the software services that will be needed to generate the M-COP, as well as services that can be derived from M-COP information to serve other communities of interest. Identification of services related to the M-COP can be considered from three perspectives:

1. GIG Core Enterprise Services (CES) needed to support the M-COP;
2. M-COP services that can be provided to other domains (each represented by a COI) on the GIG; and
3. Services provided by other domains that are needed to support the M-COP.

A separate study has been conducted to describe these services [24]. A short summary of the analysis is provided below.
5.1 GIG Core Enterprise Services Supporting M-COP

GIG CES include Enterprise Service Management, Machine-to-Machine (M2M) Messaging, Service Discovery, Identity Management (People and Device Discovery), Metadata Services, Mediation Services, and Service Security [25]. Use of GIG enterprise services by the M-COP is not expected to be unique in any way, but will reflect best practices (i.e., in accordance with established policies) for applications operating in the GIG environment that deploy services for use by other domains, while employing GIG CES and services from other domains.

5.2 Services Provided by the M-COP

The M-COP can be viewed as a general service providing data mapping, mediation, and storage. Information from other data models is interpreted with respect to mobility. For example, other users may need to find a supply route with a low probability of encountering improvised explosive devices. M-COP can be a source for this integrated product, performing a number of other information accesses on behalf of the requesting user (e.g., to access data from an “intelligence/threat” service as well as accessing a route planning service).

Example services that can be provided by or supported by the M-COP include Ground Vehicle/Unit Route Planning Products, Obstacle Locations and Status Report, Bridge Locations and Status Report, Choke Point Analysis Report, Key Terrain for Maneuver Report, Maneuver Network Analysis Product, Avenue of Approach Analysis Report, Critical Maneuver Information Report, and Areas of Unrestricted, Restricted and Severely Restricted Movement Product. It should be noted that none of these products are static, but are dynamic, with changes based on Battlefield Operating Systems (BOS), battlespace environment, and other factors.

5.3 Services Provided by Other Communities of Interest (COIs) to Support the M-COP

Realization of the M-COP will require data and services that the M-COP will expect from other domains. Winters and Tolk [26] discuss the development of some prototype services (Blue Force Tracking and Global Force Management) which can provide some of the products needed for M-COP. Examples of information that need to be obtained from other services on the GIG include Terrain Products and Data (such as locations of terrain features and facilities, current and projected soil condition, etc.); Engineer Products (such as ability to breach or emplace minefields or other obstacles); Weather Products (such as visibility and precipitation); Threat Analysis (such as known/suspected enemy locations, estimated track and enemy objective); Friendly Force Locations, Missions, Unit Boundaries, and Control Measures The Virginia Modeling, Analysis, and Simulation Center (VMASC) has developed prototype Web services for data mediation using the Command and Control Information Exchange Data Model (C2IEDM) as a common representation for data interchange across C4I and M&S systems [27]. VMASC researchers have also started to formalize the C2IEDM into class and property structures expressed in OWL [28]. Numerous C2IEDM constructs (e.g., units, obstacles, missions, boundaries, and others) meet a portion of the information requirements of the M-COP and will be reviewed in detail in the next phase of the project.

5.5 Concept Demonstration of M-COP Service

A demonstration service is being developed as part of a related project, Common Maneuver Networks. This service will explore use of the M-COP service descriptions and emerging ontology with OneSAF Objective System (OOS) as a route planning client and BTRA maneuver network products serving as a basis for routing calculations. The routing will initially accept waypoints and vehicle types as input, but will be extended, where possible, to include OOS entity behavior needs as routing constraints. Results from this work will inform further refinement of M-COP service description and continued development of the M-COP taxonomy. Figure 5.5.1 depicts the major elements of the demonstration concept.

![Figure 5.5.1. Demonstration of the Application of M-COP Web Services.](image)
6. Status and Future Work

This report presented the findings of the stakeholders’ analysis and described the top-level design of a common data model for M-COP. The stakeholders’ analysis proved to be a valuable method for prompting and collecting expert inputs for identification of M-COP information requirements. The inputs provided an excellent foundation for identification of top-level data categories for designing the M-COP data model. The tasks performed also provided insights into ontology development to guide model refinement in subsequent phases of the project, as well as providing indications of the software services that will be needed to support M-COP generation in the future GIG environment. Follow-on work will extend these ideas and also illustrate various applications of the data model.

7. References


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