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Goerger, Niki C.; Richmond, Paul; Gates, Burhman; Pace, Michael; Blais, Curtis

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Data Mapping and Ontology Design for Common Maneuver Networks

Curtis L. Blais
Naval Postgraduate School
MOVES Institute
700 Dyer Road Rm366
Monterey, CA 93943
clblais@nps.navy.mil

Dr. Niki C. Goerger
US Army ERDC
ATTN: MADN-SE, Systems Engineering, Bldg 752
United States Military Academy
West Point, NY 10996-1905
Niki.C.Goerger@erdc.usace.army.mil

Dr. Paul Richmond
US Army ERDC
CEERD-GM-M
3909 Halls Ferry Rd
Vicksburg, MS 39180-6199
Paul.W.Richmond@erdc.usace.army.mil

Burhman Gates
US Army ERDC
CEERD-GM-M
3909 Halls Ferry Rd
Vicksburg, MS 39180-6199
Burhman.Gates@erdc.usace.army.mil

Michael Pace
US Army ERDC
CEERD-IE-C
3909 Halls Ferry Rd
Vicksburg, MS 39180-6199
Mike.E.Pace@erdc.usace.army.mil

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ABSTRACT: *Current Battle Command (BC), Embedded Training (ET), and modeling and simulation (M&S) decision support systems do not share a common representation of the environment or many analysis services, including those associated with tactical maneuver data. The battlespace Common Operational Picture (COP) is therefore inconsistent across these systems, potentially leading to severe consequences from incorrect decisions about maneuver potential during training, planning, and execution of operations. True commonality is needed to enable the Army's Future Force and Future Combat Systems (FCS) by facilitating seamless transition between BC/Command and Control (C2) and models and simulations which are at the core of ET and decision support.*

As an initial effort toward resolution of this problem, the U.S. Army Engineer Research and Development Center (ERDC), the U.S. Army Training and Doctrine Command (TRADOC) Analysis Center - Monterey (TRAC-Monterey), and the Naval Postgraduate School (NPS) Modeling, Virtual Environments, and Simulation (MOVES) Institute are working to develop a common, consistent capability for assessing mobility and dynamic maneuver potential for C2 and M&S systems, to include ET. As demonstration platforms, the research utilizes (a) the Battlespace Terrain Reasoning and Awareness (BTRA) program which provides maneuver information products to the Commercial Joint Mapping Toolkit (C/JMTK) which in turn informs C2 systems and (b) OneSAF Objective System (OOS) as the designated ET platform for entity-level force-on-force simulation in FCS. Through development and application of technologies for interchange of data, information, and knowledge between systems, researchers are synchronizing representations of ground vehicle mobility/maneuver within the environment and reconciling the representations with associated behaviors. On the one hand, the approach involves development of specialized software to deal with the particular data formats of the two systems. This is the traditional point solution for establishing interchange between two systems. On the other hand, this work is also examining multiple existing data representations of maneuver networks in order to identify commonalities and abstract concepts for development of a common conceptual language that can be used to enable data interchange. The work involves researching Web standards that can assist in achieving future interoperability requirements across a broader set of systems, existing or future.

This paper describes work performed to date and challenges that are being addressed to relate the specific BTRA and OOS programs in terms of data mapping, thereby setting a foundation for future work to be performed to establish Common Maneuver Networks across diverse C2 and M&S systems through a more generalized ontology design.

1. Introduction

Current Battle Command (BC), Embedded Training (ET), and modeling and simulation (M&S) decision support systems do not share a common representation of the environment or many analysis services, including those associated with tactical maneuver data. Differences in the operational picture include, for example, inconsistent identification of mobility corridors, potential engagement areas, and travel times. The concept of operations for the Army's Future Force necessitates M&S systems be interoperable with Command and Control (C2) systems to support mission analysis and course of action (COA) development and analysis for training, planning, rehearsal and mission execution. These systems must be based on a common picture of the battlespace to be interoperable. An inconsistent Common Operational Picture (COP) of the battlespace can potentially lead to severe consequences, such as incorrect decisions about maneuver potential during training, planning, and conduct of operations. True commonality is needed to enable the Army's Future Force and Future Combat Systems (FCS) by facilitating seamless transition between BC/C2 and M&S capabilities which are at the core of ET and decision support.

As an initial effort toward resolution of this problem, the U.S. Army Engineer Research and Development Center (ERDC), the U.S. Army Training and Doctrine Command (TRADOC) Analysis Center - Monterey (TRAC-Monterey), and the Naval Postgraduate School (NPS) Modeling, Virtual Environments, and Simulation (MOVES) Institute are working to develop a common, consistent capability for assessing mobility and dynamic maneuver potential for C2 and M&S, to include ET. As demonstration platforms, the Common Maneuver Networks (CMN) project utilizes (a) the Battlespace Terrain Reasoning and Awareness (BTRA) program which provides maneuver information products to C2 systems and (b) OneSAF Objective System (OOS) as the designated ET platform for entity-level force-on-force simulation. Through development and application of technologies for interchange of data, information, and knowledge between systems, researchers are synchronizing representations of ground vehicle mobility/maneuver within the environment and reconciling the representations with associated behaviors. Project thrusts include: (a) developing a means of inserting BTRA ground vehicle maneuver networks and maneuver products into OOS; (b) developing a recommended schema for broader community use and interchange of ground vehicle maneuver networks between systems; (c) incorporating factors pertinent to semi-automated force (SAF) behaviors and functions into a consistent interoperability methodology; and (d) investigating scaling and adaptive algorithms between entity and aggregate level maneuver networks.

On the one hand, the CMN project has developed specialized prototype software to deal with the particular data formats of the two systems. This is the traditional point solution for establishing interchange between two systems.

On the other hand, the CMN effort is also performing analysis and design to examine multiple existing data representations of maneuver networks in order to identify commonalities and abstract concepts to construct a common conceptual language that can be used to improve data interchange and data processing. The work involves researching other relevant data modeling approaches and Web-based standards that can assist in achieving interoperability requirements across a broader set of systems, existing or future.

This paper describes work performed to date and challenges being addressed to specifically relate BTRA and OOS in terms of data mapping for Common Maneuver Networks, thereby setting a foundation for future work to be performed to establish CMN across diverse C2 and M&S systems through a more generalized ontology design. The scope of this paper is limited to ground vehicle mobility and mobility-related elements of the following tasks as described in the Army Universal Task List [1]: conduct tactical maneuver (ART 2.2), conduct tactical troop movements (ART 2.3), conduct mobility operations (ART 5.1), conduct countermobility operations (ART 5.2), display a common operational picture tailored to user needs (ART 7.2.3), conduct offensive operations (ART 8.1), conduct defensive operations (ART 8.2), and conduct mission tasks (ART 8.5).

The next section provides a brief overview of the nature of maneuver networks in Army parlance, BTRA and entity-level M&S. Section 3 discusses different data models for describing the networks, setting the stage for future ontology development. Section 4 summarizes the status of current work and provides recommendations and direction for follow-on efforts.

2. Maneuver Networks

2.1 Overview

This section provides an overview of maneuver and movement related to ground vehicle mobility. In discussing the development of data mappings and ontology design for Common Maneuver Networks for BC and M&S interoperability, it is important to discuss what is meant by maneuver networks for this study. Likewise, it is important to frame the discussion in relevant military terms because these terms form the foundation of Battle Command and are the basis for tasks and behaviors in military simulations. Within this context, movement and maneuver (ground vehicle) in simulations and considerations in BTRA are presented. The intent is to concentrate on issues associated with behavior of computer-generated and semi-automated forces and the use of BC systems to provide selected data and parameters to cue their behavior. Terrain representation is necessarily coupled in the discussion due to its influence on tasks and behaviors.

2.2 Maneuver Networks

In BTRA, ground vehicle maneuver networks consist of a set of nodes and edges arranged in space across an area of interest. The network is derived based on information about vehicles and terrain. The network represents the movement pathways, mobility corridors, and associated attributes, such as vehicle speed and distance, and is thus an abstraction of mobility. OOS also has a representation of a network that supports various services such as vehicle route planning for semi-automated and computer-generated forces. OOS and BTRA network attributes have some overlap but there are several differences. Likewise, the networks do not overlay precisely or completely in space based on methodologies used to build the networks. A better correlation of network information between BTRA and OOS can be achieved by mapping the networks through a common interpretation with an understanding of the implications in OOS for semi-automated and computer-generated force behaviors in conducting military operations. BTRA and OOS movement, maneuver, and attribute comparisons will be discussed later in this paper.

2.3 Military Terms and Definitions

In BC and M&S systems, movement and maneuver are assessed in accordance with tasks needed to perform operations. The Army Universal Task List (AUTL) describes the Army's tactical collective tasks within the Army's Battlefield Operating Systems (BOS) [1]. These tasks are broken down into subtasks and provide valuable information for mission-task decomposition. The AUTL tasks principally relevant in this project are the following: conduct tactical maneuver (ART 2.2), conduct tactical troop movements (ART 2.3), conduct mobility operations (ART 5.1), conduct countermobility operations (ART 5.2), display a common operational picture tailored to user needs (ART 7.2.3), conduct offensive operations (ART 8.1), conduct defensive operations (ART 8.2), and conduct mission tasks (ART 8.5).

The project is principally concerned with tasks in three BOS: the maneuver system; the mobility, countermobility, and survivability system as it pertains to mobility and countermobility; and the command and control system as it pertains to the common operational picture. From FM 3-90, Tactics [2]:

- The maneuver system "is the movement of forces to achieve a position of advantage with respect to enemy forces. This system includes the employment of forces on the battlefield in combination with direct fire or fire potential. This system also includes the conduct of tactical tasks associated with force projection."
- The mobility, countermobility, and survivability system involves mobility operations to "preserve the freedom of maneuver of friendly forces" and countermobility operations to "deny mobility to enemy forces."
- The command and control system "includes all collective tasks associated with supporting the exercise of authority and direction by a properly designated commander over assigned and available forces in the accomplishment of the mission."

It follows that operational maneuver is defined in FM 3-0 [3] as involving "placing Army forces and resources at the critical place in time to achieve an operational advantage. It is complex and often requires joint and multinational support. Deployment and intratheater movements are operational maneuver if they achieve a positional advantage and influence the outcome of a campaign or battle."

Tactical maneuver is defined in FM 3-0 [3] as winning "battles and engagements. By keeping the enemy off balance, it also protects the force. In both the offense and defense, it positions forces to close with and destroy the enemy. Effective tactical maneuver continually poses new problems for the enemy. It renders his reactions ineffective and eventually drives him to defeat."

Figure 2.3.1 below depicts selected AUTL subtasks related to the task ART 2.2 Conduct Tactical Maneuver. It further shows the types of movement techniques that are used in conjunction with combat formations. Formations and movement techniques are selected based on considerations for terrain and weather effects as well as for enemy capabilities. Note, ART 2.2.5 specifically calls out the need to exploit the terrain.

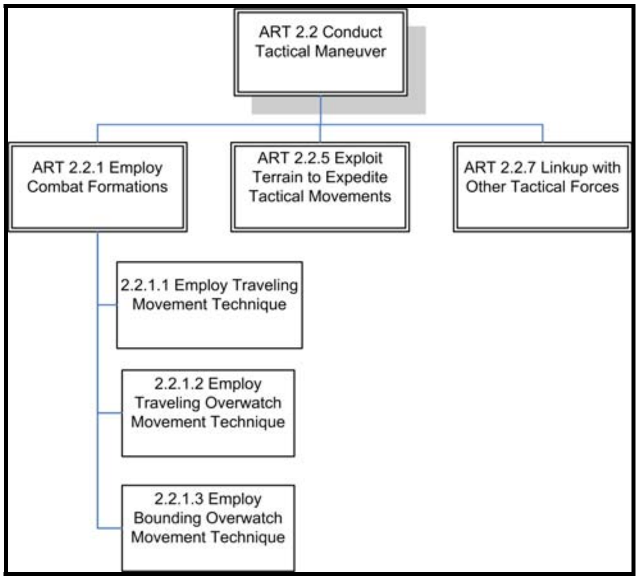


Figure 2.3.1. AUTL Task 2.2, Selected Subtasks, and Relationship with Combat Formations and Movement Techniques [1].

Combat formations are used in conjunction with movement techniques in operations and are based on mission, enemy, terrain and weather, troops, time available, and civil considerations (METT-TC). Formations include column, line, and wedge, among others [2]. For example, a wedge formation is generally employed when contact with the enemy is possible or expected, but the enemy location is uncertain. It is also useful when enemy contact is not expected, movement is through open terrain, and there is a need for speed. Thus, considerations relevant to mobility and terrain include mobility corridors, cover and concealment, and vehicle speed. The three movement techniques are traveling, traveling overwatch, and bounding overwatch. Like combat formations, these are selected based on likely contact with the enemy, need for cover and concealment, need for speed, and conduciveness of the terrain.

Figure 2.3.2 shows subtasks associated with AUTL task ART 2.3 Conduct Tactical Troop Movements. A form of troop movement generally precedes an offensive operation. While there are four forms of tactical troop movements, our research is limited to conduct administrative movement, conduct tactical road march, and conduct an approach march. ART 2.3.1 Prepare Forces for Movement deals with preparation (as the name indicates) rather than the act of moving.

Per FM 3-0, Operations [2]:

- "An administrative movement is a movement in which troops and vehicles are arranged to expedite their movement and conserve time and energy when no enemy interference, except by air, is anticipated. Administrative movements occur in areas where enemy forces do not pose an immediate threat to operations and heightened security is not necessary."

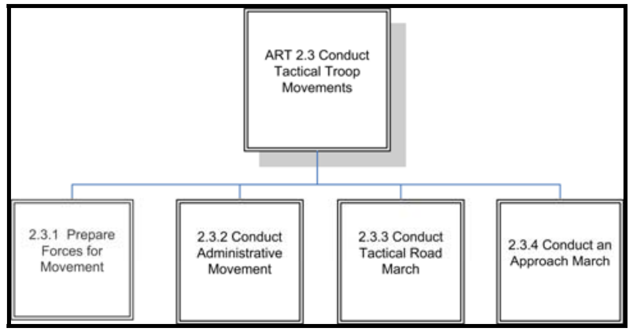


Figure 2.3.2. AUTL Task 2.3 Conduct Tactical Troop Movements and Subtasks [1].

- "A tactical road march is a rapid movement used to relocate units within an area of operations to prepare for combat operations. Although contact with enemy forces is not anticipated, security against air attack, enemy SOF, and sympathizers is maintained and the unit is prepared to take immediate action against an enemy threat. Tactical road marches occur when a force must maintain security or when movements occur within range of enemy influence. Commanders may still execute tactical road marches in low-threat environments to maintain C2 and meet specific movement schedules."
- "An approach march is the advance of a combat unit when direct contact with the enemy is intended. Soldiers are fully or partially deployed. Commanders direct an approach march when they are relatively certain of the enemy location and are a considerable distance from it. They decide where their forces can deploy into attack formations that facilitate the initial contact and still provide freedom of action for the bulk of their forces. In contiguous AOs [areas of operation], a passage of lines often precedes or follows an approach march."

From the above descriptions, for planning, training, mission rehearsal and eventual mission execution, the important concept is that predictions of the time it takes to reposition forces or to close with the enemy forces at the desired location are critical and thus must be as accurate as possible. Moreover, these predictions must be consistent between planning tools (such as BTRA) and training/rehearsal systems (such as OOS).

2.4 Movement/Maneuver in Simulations

At its simplest, modeling of movement and maneuver in simulations is based on a rate of movement over a planned route. The movement rate may be specified by the user or based on vehicle performance parameters. The route may involve a number of segments over various types of road surfaces or terrain. To aid the user in planning movements, some simulations provide automated route planning (e.g., “best” route between two points in terms of time or concealment, or both) and estimates of vehicle or unit speeds between intermediate points.

A review of movement algorithms in Army models suggests that important performance parameters for ground vehicle modeling are speed, acceleration/deceleration, turning rate and radius, collisions (avoiding), and modeling of environmental effects (rain, snow, fog, etc.) [4]. Additionally, the same report states that mobility operations (obstacle reduction by maneuver or engineering units), formations (the alignment of forces in movement), dispersion or reaction to fires, and the effects of suppression (direct/indirect fires and smoke) on movement/maneuver are also important.

Historically, model fidelity has determined the extent to which these effects are represented. OneSAF Testbed Baseline (OTB) models many of the above performance and operational effects. OOS will have the same or better model fidelity.

Courtemanche [5] presented an analysis of vehicle maneuver modeling in semi-automated forces (SAF) and computer-generated forces (CGF) simulation applications. Figure 2.4.1 shows his summary of the elements of a general maneuver approach taken by Modular SAF (ModSAF) and Close Combat Tactical Trainer (CCTT).

In OOS, entities and units are given “missions” that contain tasks; for example, “move to a point” is a task. OOS will use the Standard Mobility (STNDMob) Application Program Interface (API) [6] for vehicle performance calculations. OOS terrain is based on point, linear and aerial features. Each feature has a set of attributes, some of which can have a dynamic influence on vehicle performance. For example, soil strength as measured by cone index, snow depth, presence of ice, etc.

The following task descriptions were developed for movement within OOS based on Army doctrine:

- Conduct Tactical Road March – used for fast on-road movement when enemy contact is not anticipated.
- Move Tactically Bounding Overwatch – used when enemy contact is anticipated.
- Move Tactically Traveling – used when speed is needed and enemy contact is not anticipated.
- Platform Move – basic move to point task.

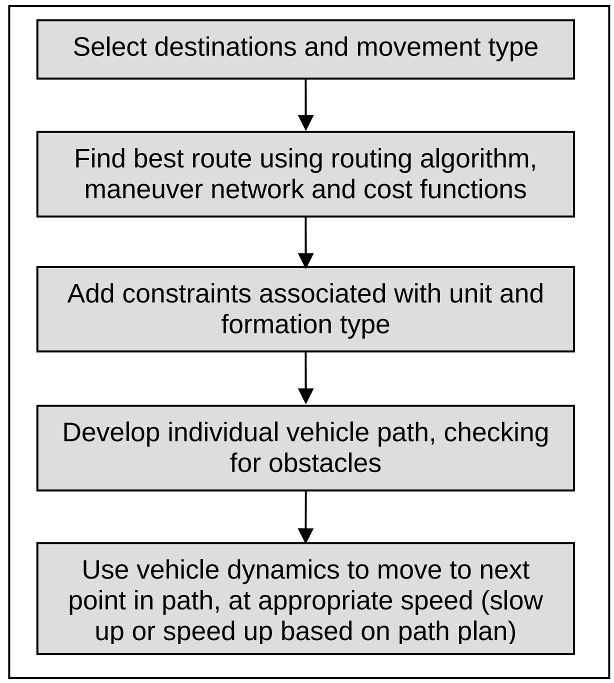


Figure 2.4.1. Common Elements in Maneuver of Ground Vehicles in a SAF Simulation [5].

Note that the interoperability issue is not limited to common representation of data to facilitate interchange, but common representation of behaviors as well. As a first step toward higher levels of interoperability across BC and M&S systems, the systems must move from initial syntactic exchange of data to common semantic representations of data. Work to date has achieved the first level through software manipulation of the data from BTRA for input to OOS as a point-to-point solution and has made progress toward the second level by exploring alternative representations for a common data model that can be used by both systems. Significantly, though, the descriptions of movement and maneuver behaviors also need to be consistent across the systems; that is, even with consistent data, what the systems do algorithmically with the data needs to be consistent as well (pragmatic interoperability); this is moving toward full conceptual interoperability where a common view of the world is established (refer to Tolk’s Levels of Conceptual Interoperability Model [7]).

2.5 BTRA for Route Planning

BTRA is based on a geographic information system (GIS) and currently operates in ESRI's ArcMap product (http://www.esri.com), with future implementation into the Commercial Joint Mapping Toolkit (C/JMTK). Currently, the Combined Arms Planning and Execution Monitoring System (CAPES) and the Maneuver C2 (MC2) system use the products generated by BTRA. CAPES and MC2 provide an advanced suite of decision aids that enable collaborative, execution-centric, mobile C2 supporting the Combined Arms Commander. ArcMap is raster based (grid points) with associated attributes. For mobility analysis, areas of similar attribution are linked together to form "edges" and "nodes" (intersections). Some attributes are grouped into classes and are represented by a single value.

BTRA produces a network (map) of linked edges and nodes which have attributes associated with movement and movement planning. This is what is referred to as the *maneuver network* in BTRA. The Software Components Requirements/Functional Description document [8] describes the input to and output from the various BTRA software components. In particular, the Ground Maneuver Network component provides the ability to create a Mounted or Dismounted Ground Maneuver Network that can be used in maneuver analysis applications. For example, Table 2.5.1 lists BTRA Mounted Ground Maneuver Network attributes.

Table 2.5.1. BTRA Mounted Maneuver Network Attributes

Attribute	Data Type	Description
OBJECTID	AutoNumber	ESRI Unique ID
SHAPE	OLE Object	ESRI Line Geometry
Enabled	Short Integer	On/Off Switch
EDGE_CAT	Long Integer	Type of network edge used for weights (concealment inherited from NoGo) (Edge_Code DOMAIN)
EDGE_WID	Long Integer	Corridor width used for capacity analysis (on and off road)
EDGE_LEN	Short Integer	Length of Edge in meters (BTRA-Distance)
OFF_RD_SHRT	Double	Weighted Cost Field for Off road shortest route The weight mainly uses Mobility Corridors (EDGE_CAT=100), but is heavily weighted to use roads, bridges or other edges as necessary to solve route.
ON_RD_SHRT	Double	Weighted Cost Field for On road shortest route The weight mainly uses Roads (EDGE_CAT 400-450), but is heavily weighted to use mobility corridors or other edges as necessary to solve route.
VEH1_SPD, VEH2_SPD, VEH3_SPD, VEH4_SPD, VEH5_SPD, VEH6_SPD, VEH7_SPD, VEH8_SPD, VEH9_SPD, VEH10_SPD, VEH11_SPD, VEH12_SPD	Short Integer	Vehicle Speeds from STNDMob API for each edge for 12 vehicle categories (i.e., High/Medium/Low Mobility Tracked, High/Medium/Low Mobility Wheeled, etc. – see [8])
VEH1_TIME, VEH2_TIME, VEH3_TIME, VEH4_TIME, VEH5_TIME, VEH6_TIME, VEH7_TIME, VEH8_TIME, VEH9_TIME, VEH10_TIME, VEH11_TIME, VEH12_TIME	Double	Weighted Cost Field for Fastest route for the 12 vehicle categories
OFF_RD1_FAST, OFF_RD2_FAST, OFF_RD3_FAST, OFF_RD4_FAST, OFF_RD5_FAST, OFF_RD6_FAST, OFF_RD7_FAST, OFF_RD8_FAST, OFF_RD9_FAST, OFF_RD10_FAST, OFF_RD11_FAST, OFF_RD12_FAST	Double	Weighted Cost Field for Fastest Off Road route for the 12 vehicle categories using dynamic soil conditions. The weight mainly uses Mobility Corridors (EDGE_CAT=100), but is heavily weighted to use roads, bridges or other edges as necessary to solve route.
On_RD1_FAST, On_RD2_FAST, On_RD3_FAST, On_RD4_FAST, On_RD5_FAST, On_RD6_FAST, On_RD7_FAST, On_RD8_FAST, On_RD9_FAST, On_RD10_FAST, On_RD11_FAST, On_RD12_FAST	Double	Weighted Cost Field for Fastest On Road route for the 12 vehicle categories. The weight mainly uses Roads (EDGE_CAT 400-450), but is heavily weighted to use mobility corridors or other edges as necessary to solve route.
DYNAMIC_COST	Double	Used to Accumulate Cost at run time (either Distance or Time cost depending on choice of applied at run time)

Attribute	Data Type	Description
MET_ID	Long Integer	Relate weather changes from FASST-C to Network
MOB_ID	Long Integer	Relate STNDMob Speed Tables to Network
SHAPE_Length	Double	Length of Edge in Decimal Degrees (note: BTRA uses EDGE_LEN field above)
Conceal_Cost	Double	Weighted cost for concealment

For vehicle speed computations, BTRA uses the STNDMob API (version 3.2.3.0) provided and maintained by the ERDC. As OOS moves to the STNDMob API, one important area of difference will be elminated.

2.6 Issues Associated with Consistent Movement

Table 2.6.1 summarizes a preliminary assessment (work in progress) of issues relating to the effects of vehicle parameters, behavior, and operations on movement and maneuver in BTRA and OOS. A good example of logical differences in handling of routes is that BTRA finds routes using the average speed (average between up slope and down slope), whereas OOS uses speed calculations based in part on the pitch of the vehicle (regardless of grade). Such algorithmic differences are also part of the overall semantics of the domain that needs to be addressed in the effort to create interoperability at the pragmatic and conceptual levels.

Table 2.6.1. Effects of Vehicle Parameters, Behavior and Operations on Movement in BTRA and OOS

Parameter/Operation	BTRA	OOS
Maximum Vehicle Speed	Will use STNDMob, fidelity level 3; slope in classes, edge speeds in classes	Will allow different levels of STNDMob levels of fidelity, slope effects (continuous) calculated based on vehicle position and orientation
Acceleration/Deceleration	Not modeled	Usage unknown
Turning radius/turning rate	Usage unknown	STNDMob includes turning speeds
Collisions	Edges should not be generated which will include collision with fixed terrain objects; collisions between entities cannot be considered	Collisions will be avoided, speeds may be slowed to avoid, or time expended in maneuvering around objects (near term route planning)
Environmental effects	Terrain state is predicted based on climate data or real time weather forecasts and reflected in STNDMob speed predictions	The OOS environmental data model contains attributes associated with terrain state; how this data will be populated is unknown
Delays caused by obstacles: Bypass, Bull through, Deliberate breach • Bypass • Bull though • Deliberate breach	Obstacles can be designated on the map, and can be avoided during analysis; unknown whether or not “bull through” or “deliberate breach” effects are represented	OOS will most likely need to have specific tasks and reactions defined by the user for each delay time
Maneuver form: envelopment, turning movement, infiltration, penetration and frontal attack	Way points can be set so that an end point can be reached in a way mimicking the form of maneuver	Set up by using movements to/through a series of points
Formations and Tactical Movement type: • Road March • Cross Country Formations • Bounding Over Watch	The effect of speed on formations is determined by selecting the vehicle type or class within the unit having the poorest movement performance characteristics	During movement, vehicles can speed up within limits to maintain spacing
Dispersion or reaction to fire	Not modeled	Currently unknown, but entities can be set to react to fire
Suppression (direct/indirect fires, smoke, NBC to prevent effective fires)	Unknown effect	Unknown effect

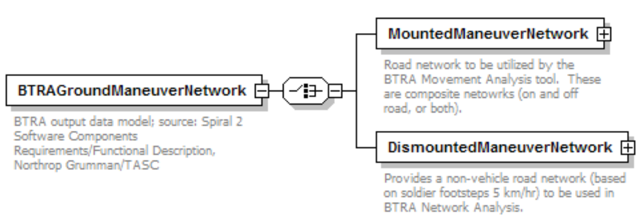
3. Alternative CMN Data Representations for Design of Interchange Mappings and a Domain Ontology

3.1 Overview

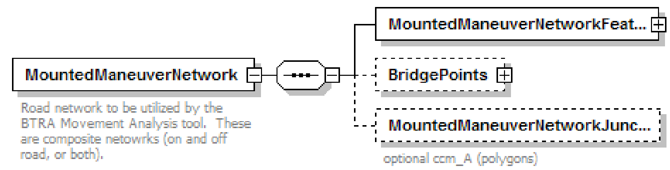
As introduced earlier, commonality in data is the foundation for interoperability at a syntactic level (i.e., data can be exchanged in standard formats). For higher levels of interoperability, not only the data but also its context needs to be standardized through a common reference model, followed by commonality of usage (algorithms and logical inference) for knowledge-level interoperability. Current work is addressing these levels of interoperability and providing a basis for follow-on efforts to develop a common ontology for a Mobility COP. As an "explicit specification of a conceptualization" [9], the ontology will provide the vocabulary and necessary conceptual interrelationships to permit greater automation in data interchange and data processing. This effort will apply current and emerging Semantic Web technologies [10]. The purpose of the Semantic Web is to develop standards that will facilitate transformation of the raw data content of current web-based architectures into an actionable knowledge base. The resulting standardization will enable greater interoperability of mobility data and functionality across C2 and simulation systems likely to be implemented in web-based net-centric architectures in future operational systems.

3.2 XML Schema Design for BTRA Maneuver Networks

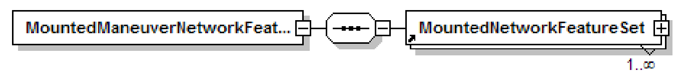
As a basic starting point in the CMN project, the team designed an XML Schema representation of the BTRA Ground Maneuver Network data. The top-level structure defined in the schema is shown below.



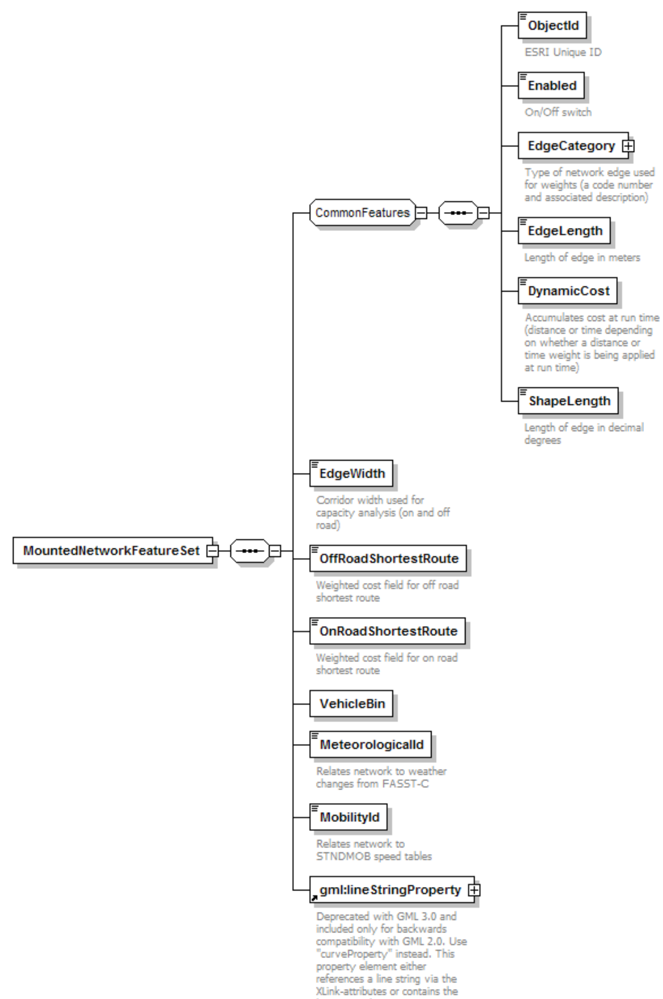
The structure offers a choice between a Mounted Maneuver Network or a Dismounted Maneuver Network. While this structure only supports description of a single network in a compliant XML document, it can easily be changed to allow one or more networks, of either kind, to be contained in a single document. The Mounted Maneuver Network data is structured as follows.



The `MountedManeuverNetworkFeatures` element contains one or more feature sets as shown in the structure below.



The `MountedNetworkFeatureSet` element, shown below (refer to Table 2.5.1 for data types and descriptions), attempts to capture the information provided in Table 2.5.1 and reference [8] and reflects a similar structure seen in early transformation work (ESRI Shape file to XML) performed in mid-2004.



In the data structure for each type of network, features and geometry are expressed for each edge of the network, again in accordance with the example output reviewed earlier in the project.

Note that the `CommonFeatures` element in the `MountedNetworkFeatureSet` structure is a group of features that are found in both the Mounted Maneuver Network and Dismounted Maneuver Network data structures. Note also the use of a selected portion of the well-established Geographic Markup Language (GML) [11] to provide an XML representation of the network geometry through the use of the `gml:lineStringProperty` element at the bottom of the `MountedNetworkFeatureSet` schema structure shown above. An advantage in the use of XML is the ability to combine XML vocabularies defined by multiple schemas, while retaining the ability to validate the content of the resulting XML documents against the structure and content rules found in those schemas. This is used to advantage in the above generic BTRA Maneuver Network XML document structure since a portion of the content uses the GML description of the network. That portion is identified by the use of the GML namespace and validates against the established GML schema documents.

Having a generic description of the data provides a foundation for interchange across a variety of representations, particularly other XML-based languages. There are a number of established data models with existing or emerging XML representations that are under investigation for use in the transfer of maneuver network information. Data mappings across the models can be documented and implemented using the Extensible Style sheet Language Transformations (XSLT), itself an XML language [12].

3.3 Military Scenario Definition Language

The Military Scenario Definition Language (MSDL) is an XML representation of scenario data developed for OOS and under evaluation for broader application in the M&S community, with possible application to the C2 community as well [13]. In the past, scenario data have been tightly coupled to the simulations or C2 systems for which the data were designed, making interchange and sharing of scenario data bases costly and difficult to achieve. The M&S and C2 communities need a standard format supporting initialization of a variety of systems. A Simulation Interoperability Standards Organization (SISO) MSDL Product Development Group is expected to be launched in the Spring 2005 workshop to progress toward the establishment of MSDL as a standard for M&S development.

MSDL describes initialization data for a military scenario consisting of a description of the initial state of a military situation plus planned actions (e.g., planned air missions, fire missions, ship-to-shore movement, etc.). MSDL offers a way to capture the military scenario in an unambiguous format for use by a variety of tools or systems to create the military scenario. MSDL is defined by an XML schema to enable applications (M&S or C2) to exchange the military portions of scenarios with other applications. The schema is partitioned into logical sub-schemas describing plan, environment, force structure, options, task organizations, installations, overlays, tactical graphics, Military Operations Other Than War (MOOTW) graphics, and threats. This partitioned design facilitates extension of the language when necessary to capture the full breadth of military scenario information.

The CMN team is investigating the structure of the MSDL to determine data commonalities that may exist, allowing for design of an XSLT document to map from the above BTRA Maneuver Network XML format to the portions of an MSDL scenario file relating to the maneuver networks. While MSDL provides a broad and expressive language for describing the forces and activities in a scenario, there is no way to directly describe the maneuver network with MSDL. Moreover, fundamental differences in the data models between BTRA and OOS prevent most of the data from being directly interchangeable. Because MSDL is largely based on MIL-STD-2525B [14], developers adopted the route representation approach provided in that standard. All routing detail is therefore specified in the `TacticalGraphics` element of MSDL. That data structure includes a Line Symbol which may be able to describe the linear geometry of the network, and certain other BTRA data may be mappable to values in the MSDL, such as the `EdgeWidth` feature in the BTRA data structure described in paragraph 3.1 to the width of the line (i.e., `Width` element of the `LineSymbolModifiers` element) in MSDL. The semantic equivalence of such values needs to be further investigated.

3.4 Command and Control Information Exchange Data Model

The Command and Control Information Exchange Data Model (C2IEDM) is a standard NATO model developed to promote data interoperability across the command and control systems of multiple countries. The model is managed and maintained by the Multinational Interoperability Programme (MIP) [15]. C2IEDM is rapidly gaining acceptance in US C2 and M&S communities, with possible application as the ontological layer for the Global Information Grid (GIG) [16].

C2IEDM provides an abstract data model that can be used to describe all objects of interest in the battlespace, including organizations, persons, equipment, facilities, geographic features, weather phenomena, and military control measures such as boundaries and routes. For CMN purposes, the abstractions in C2IEDM can be used to describe general aspects of the maneuver networks. For example, a route is defined in C2IEDM as a control feature within the `OBJECT-ITEM` hierarchy. Each `OBJECT-ITEM` can have an associated `LOCATION` that can be identified as a `LINE` which can be defined as multiple segments. A speed attribute is provided for each `OBJECT-ITEM` and `LOCATION` association, which can partially capture speed information from the BTRA Mounted Maneuver Networks data. Note also that the C2IEDM model has specific OBJECT-ITEM entries for bridges, providing a direct transfer of some of the `BridgePoints` data from the BTRA Mounted Maneuver Network data model to C2IEDM structures. Further work is needed to specify the mappings across the two representations.

XML Schema representations of the C2IEDM are now available from the DoD Metadata Registry (http://diides.ncr.disa.mil/xmlreg/user/index.cfm). Work is in progress to map BTRA Maneuver Network data to C2IEDM constructs. The next step is transfer of data from the C2IEDM structures to OOS through the MSDL; that is, C2IEDM becomes an intermediate data format for transferring information from BTRA to OOS. By developing interchange mechanisms between BTRA and C2IEDM, and between C2IEDM and OOS, the data flow can become bi-directional. This is needed when actions occurring in the simulation (e.g,. battle damage or change in weather) affect the maneuver network, requiring an update to the processing performed by BTRA. The data interchange will face similar limitations as described in paragraph 3.2 due to fundamental differences in network representations, but provides a workable starting point for improved interoperability. With C2IEDM as an intermediate form for the maneuver network data, that information also becomes available for use by the growing number of U.S. and coalition C2IEDM-enabled systems. Researchers at the Old Dominion University/Virginia Modeling, Analysis, and Simulation Center (ODU/VMASC) are creating a data exchange service using C2IEDM as the intermediate language [17]. The CMN project may be able to leverage that work to facilitate development of interchange mechanisms between BTRA and OOS, and other systems in follow-on work.

Recognizing the maturity of the C2IEDM and its acceptance as the reference model for military information exchange by all participating MIP nations, it may emerge as the best foundation for a CMN data model that would have broad applicability across multinational C4I and M&S systems. Processes and procedures are in place in the MIP community to enable extensions to the model where needed so that information necessary for CMN that cannot currently be represented in the model can be proposed as additions to the C2IEDM specification. Continuing work on the CMN effort will assess what can and cannot be represented with the current version of C2IEDM in order to recommend such extensions to the model.

3.5 Battle Management Language

The Battle Management Language (BML) is defined as an unambiguous language for commanding and controlling forces and equipment conducting military operations and for providing situational awareness and a shared, common operational picture [18]. BML is intended to become a standard language that can be used for real and synthetic troops and for future robotic forces. Whereas MSDL targets the initialization of simulation systems, BML focuses on the description of executable tasks and assigning these tasks to military entities. A key area of overlap in the two languages appears to be in the representation of planned missions and tasks.

The SISO has initiated a Coalition BML Study Group to produce a formal specification of the language. A prototype XML representation of BML was developed in 2004 [19] for demonstration of web-based interoperability concepts promoted by the Extensible Modeling and Simulation Framework (XMSF) project [20]. As a prototype representation, it has not yet been possible to obtain the XML schema for investigation in the CMN work. However, the BML project is also considering use of C2IEDM as its underlying reference model, which would make development or refinement of an XML representation of BML and investigation of interchange with a CMN representation in that form, no longer necessary. Refer to [21] for additional discussion of the relationships among MSDL, BML, C2IEDM and related efforts.

3.6 Common Maneuver Networks Domain Ontology

Conduct of the CMN project makes it clear that significant human effort is needed to bring even two specific systems, BTRA and OOS in this case, into some degree of alignment. While such effort is worthwhile and should continue, greater benefit will be obtained in the long run from establishing standard practices to build data representation frameworks at the outset in such a way that software can automatically make these associations. This is not to say all systems need to use precisely the same vocabularies, but all systems should begin to describe their data more completely so that the semantics can be clearly understood and processed by software; i.e., describing the data in terms of concepts that all developers (and their software) hold in common. There are likely to be a variety of ways of expressing the abstract conceptual layers as well, but mechanisms must be developed to relate the different representations. Developers need to be able to use different modes of expression, but provide sufficient content in the expression to ensure unambiguous interpretations at the conceptual level. Such a framework will permit greatest flexibility in system developments while ensuring a high degree of interoperability in the fielded systems without explicit efforts to create single pair data interchange. The goal is to achieve seamless "plug-and-play" interoperability at the conceptual level.

The challenge is to build stronger semantic content into the data so that software can work with the information more effectively. The development of ontologies for knowledge representation is a major research area addressing this challenge. In particular, the Semantic Web is an effort to establish web-based standards to enable software to effectively interpret and process data.

The vision of the Semantic Web is to create "an extension of the current Web in which information is given well-defined meaning, better enabling computers and people to work in cooperation" [22]. Systematic logic about a domain can be constructed to better enable software to reason about the data automatically.

An ontology "defines the common words and concepts (the meanings) used to describe and represent an area of knowledge" [23]. The various XML representations we have discussed in this paper certainly provide the "words" (the XML elements and attributes) and even some level of meaning, at least to the extent that the element and attribute names chosen are meaningful to human readers. Moreover, the XML schemas define valid document structures and content, the latter through restrictions on the data that can be entered into the associated XML document. However, this information alone does not sufficiently specify the *meaning* of the words. To infer meaning, software needs information about the concepts and relationships between and among concepts. More completely, an ontology describes (also from [23]): classes (general things) in the domain of interest, instances (particular things), relationships among those things, properties (and property values) of those things, functions of and processes involving those things, and constraints on and rules involving those things. In particular, a CMN domain ontology will describe rules and logic constituting business processes that are established across the community of interest for CMN data.

The key consideration is the ability to perform accurate reasoning on the information described by the ontology. Even with robust and well established reference data models such as the C2IEDM, there is insufficient information in the model to support fairly basic reasoning, such as determining logical, temporal, or physical planning conflicts. For automated reasoning, it is not enough to provide an enumeration list of values for a data element without providing some semantic content about the terms used in the enumeration.

Pioneering work on development of ontologies for OOS is described in [24] and [25], including preliminary representation of behaviors that need to be evaluated in light of CMN goals. Such efforts begin to extend the representations to higher semantic levels, moving beyond XML and XML Schema representations to descriptive layers that will enable software to perform reasoning on the data, setting the stage for automation of processes that have been heavily human-centric in the past.

4. Status and Future Work

The CMN team has succeeded in developing prototype software to directly transform maneuver network data from BTRA into route data for input to OOS and is continuing to study the BTRA and OOS data models to identify common elements and concepts. The team has explored various alternative representations of the BTRA and OOS data, including representation as generic XML structures defined by an XML Schema. To improve the current state of data exchange, we recommend that BTRA maneuver network products be exportable to C2IEDM structures (through software or style sheet transformation) as an intermediate structure for transformation to inputs (MSDL) to OOS.

Follow-on work will focus on generation of a Mobility COP from/for C2 and M&S systems through ground vehicle mobility-related parameters and products to enable Future Force assured mobility. Currently, common terminology, data and information formats or translators are required, but do not exist. Within C2 systems, required data is spread throughout systems/echelons and numerous situation reports. There is also the possibility of deriving data for the COP from situation reports (SITREPs).

The follow-on effort will begin with clear delineation of requirements for the components of the Mobility COP. The team will conduct an analysis of ground vehicle movement parameters, objects which affect ground vehicle movement and algorithms within several systems, such as the Army Battle Command System (ABCS), FORCEXXI Battle Command Brigade and Below (FBCB2)/Blue Force Tracker (BFT), and OOS to identify commonalities and differences. The team will investigate existing and emerging Web technologies, including Web Services and Semantic Web concepts, to identify standards needed to achieve Mobility COP requirements.

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Author Biographies

CURTIS L. BLAIS is a member of the Research Faculty in the Modeling, Virtual Environments, and Simulation (MOVES) Institute at the Naval Postgraduate School (NPS), Monterey, California. He is working a number of research efforts in application of web-based technologies to military modeling and simulation, including the Extensible Modeling and Simulation Framework (XMSF), Military Operations Other Than War (MOOTW) Flexible Asymmetric Simulation Technologies (FAST) Toolbox, and Common Maneuver Networks (CMN). He received an M.S. and B.S. in Mathematics from the University of Notre Dame, and is currently a Ph.D. candidate in MOVES at NPS.

DR. NIKI C. GOERGER is a research engineer with the U.S. Army Engineer Research and Development Center (ERDC). Her expertise is in the area of physics-based and effects-based representation and quantitative analysis in modeling and simulation (M&S) for military applications. She is currently a research associate at the United States Military Academy and serves there as the Academy's Defense Model and Simulation Office Visiting Professor (M&S) with research tracks in lifecycle acquisition management, M&S and C4ISR interoperability, and physics-based representation in urban operations M&S.

PAUL W. RICHMOND, Ph.D., P.E. is a mechanical engineer at the U.S. Army Corps of Engineers, Engineer Research and Development Center (ERDC) where he develops ground vehicle mobility models for use in simulations, simulators and performance analysis models, specifically related to terrain interaction and off-road performance.

BURHMAN GATES began his career at the U.S. Army ERDC in 1990. He works in the areas of testing, modeling, and transfer of vehicle terrain interaction models. He is a member of SAME, IEEE, and the National Society of Professional Engineers and has served as president of the Mississippi Engineering Society Vicksburg Chapter. Mr. Gates received his Bachelor of Science degree in Electrical Engineering from Louisiana State University.

MICHAEL PACE is a civil engineer with the U.S. Army Corps of Engineers, Engineer Research and Development Center (ERDC) where he researches systems interoperability and develops methods of modeling urban infrastructure to support operations in an urban environment for use in military simulations and decision aids. He received his BS and MS degrees in Civil Engineering from Mississippi State University.