Environmental Data Modeling for Simulation System Requirements Specification

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Abstract

An environmental data model (EDM) explicitly captures the phenomena (e.g., features) in the natural environment, the qualifying attributes of those phenomena, and the implicit relationships among phenomena. As such, the environmental data model is a key element of a simulation system – at the program specific level, it describes the geospatial environment in which the simulation takes place and with which all entities interact. These interactions serve as a compelling reason to establish the program environmental data model early in the development process, *i.e.,* during system requirements analysis. In practice, it is best to define the data model as one of the first requirements analysis activities due to its broad impact throughout the overall system. Important system elements affected are the behavioral and dynamic models and hence the overall effectiveness of the system in providing the required capabilities, be they training, analysis, or acquisition based. Historically, requirements analysis has involved analysis of a system's intended operational use and the entities to be modeled. Complex systems might characterize hundreds of unique enitity types. Ideally, all entities to be modeled will have a consistent representation of the world. The ability to achieve this is facilitated by the EDM. Additionally, system development efforts will be better focused if the program EDM is developed early in the system lifecycle.

Until recently, environmental data modeling has been *ad hoc*, with the data models captured only in implicit fashions such as in source code or data files, if at all. The Army Warfighter Simulation (WARSIM) 2000, a component of the Joint Simulation System (JSIMS), defined a Terrain Common Data Model (TCDM) for use throughout the JSIMS Alliance. The Army Synthetic Natural Environment (SNE) Science and Technology Objective (STO) has developed a Common Data Model Framework (CDMF) to promote the comparison of program specific EDMs and support the higher resolution requirements of the OneSAF Test Bed and the Close Combat Tactical Trainer (CCTT). The Reference EDM which will ultimately result from the unification of these program-specific EDMs will provide an important infrastructure for achieving environmental interoperability within the community of land combat simulations. Additionally, the SNE STO is addressing critical system-of-systems interoperability issues by developing explicit data modeling technology to support the concept of representing environmental phenomena at multiple levels of resolution. In a related activity, the Defense Modeling and Simulation Office (DMSO) is extending the CDMF concept from terrain to the ocean and atmosphere domains. Creating these EDMs for Ocean and for Atmosphere supports the overall goal of establishing a general Environmental Data Model composed of environmental sub-domain EDMs (terrain, ocean, atmosphere and space) from which user community Reference EDMs and program specific EDMs would be generated as profiles.

This paper provides an overview of the environmental data models developed to date, focusing on the importance of developing such a model early in the simulation system development process. The general process for developing such a data model is also described.

INTRODUCTION

The activity of explicit environmental data modeling is relatively new to the modeling and simulation (M&S) community but has been a long established practice in Mapping, Charting and Geodesy (MC&G). There are many forms of environmental data models, ranging from the conceptual and abstract to the physical and concrete. Examples of the former are the Joint Meteorology and Oceanography Conceptual Data Model (JMCDM) and the United States Imagery and Geospatial Information System (USIGS) Conceptual Data Model (UCDM) [1] components of the Defense Data Model (DDM). Examples of the latter are specifications for geospatial data products content and format (*e.g.,* the Vector Map (VMAP) product line, Digital Terrain Elevation Data (DTED) at various resolution levels, Foundation Feature Data (FFD), levels of Digital Topographic Data (DTOP), and the libraries of Digital Nautical Charts (DNCs)) and the recent JSIMS Terrain Common Data Model (TCDM) [2]. The environmental data models with which we are concerned are often described as *logical* data models. For a particular program or application, a logical environmental data model is a specification of the environmental phenomena/features, their qualifying attributes, implicit and explicit relationships between the phenomena/features (including their organization into classes or coverages), and, for each feature/attribute pair, the explicit range of allowable attribute values.

Additionally there are meta-data models that have been developed to describe how the entity information should generally be represented, but allowing multiple implementations to be supported. Examples of the meta-data models are the NIMA Vector Product Format (VPF) and Standard Linear Format (SLF), the Object Model Template (OMT) used in the High Level Architecture (HLA) for M&S, and the SEDRIS Data Representation Model (DRM).

The environmental data model is a key element of a simulation system. It describes the geospatial environment in which the simulation takes place and with which all entities interact. These interactions serve as a compelling reason to establish the environmental data model early in the development process, *i.e.,* during system requirements analysis.

Ideally, the simulated physical environment *appears* the same to each simulation system element (*e.g.,* vehicle model, behavior model, sensor model). The task of bounding just what that environment is (what it includes, how objects are described, object relationships, etc.) can be considerable. In general, simulation systems are bound to requirements identified through one or more systems requirements specifications (*e.g.,* operational, functional, technical). The depth of a requirements base is highly variable across the spectrum of simulation elements and hence requires some level of requirements analysis. Resulting derived requirements may, in turn, impose additional requirements on related system elements. Key to the development of an environmental data model is the ability to distill out pertinent object types and their attributes, recognizing common needs across system elements. Additionally, some level of understanding of the overall design of each element is necessary both in the context of understanding the data required and how it is used within the system.

Semantics and Syntax

A data model requires both semantics and syntax. The phenomena/features and attributes of the physical environment need unambiguous and agreed-upon meanings as well as a coding schema to support machine parsing. The Digital Geographic Information Exchange Standard (DIGEST) Feature and Attribute Coding Catalog (FACC) [3], a NATO standardization agreement (STANAG 7074), was initially used as the language for the JSIMS TCDM. However, FACC does not fully cover the spectrum of environmental data now required in M&S applications. The Environmental Data Coding Specification [4] (EDCS) was initiated as a part of the DMSO-sponsored SEDRIS project and will eventually provide a code for each object and attribute likely to be included in any simulation database describing the physical environment. The EDCS is becoming an international standard under processes established by the International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC).

The syntax of a data model can range from free text (*e.g.,* published NIMA product specifications) to IDEF1X (*e.g.,* UCDM). Whatever the form used for disseminating a data model, maintaining the data model in a relational database supports queries, reports, comparisons, searches, configuration management, derivation of application runtime data formats and schemas, and direct access to its content by diverse software applications.

HISTORICAL APPROACH

Previous military simulation systems have designed and implemented their own unique data models. This has, unfortunately, been nowhere more true than regarding terrain environmental data. The STRICOM Close Combat Tactical Trainer (CCTT) and DARPA Synthetic Theater of War (STOW) JointSAF, for example, have different terrain data models despite their high degree of similarity with respect to terrain data requirements and incorporated military equipment, unit, and task models. As a result, it is both harder to establish interoperability between these two systems either pre-runtime through the sharing of common terrain databases or during execution through shared models of dynamic terrain.

The development of an EDM for Terrain for Modeling and Simulation (M&S) applications is driven by a number of factors. These include system-level terrain requirements (usually incomplete), system-level military model requirements (usually evolving and ill-defined), system runtime constraints (usually resource-limited) and terrain source data availability (usually insufficient). Given these complex and conflicting influences, program specific terrain data models in M&S have tended toward *post facto* specification, if they are explicitly defined at all.

As a result, M&S applications currently use a wide variety of run-time program specific "native" data models for representing terrain data. This multiplicity of native terrain data models hinders not only interoperability during pre-simulation initialization, but also at runtime (*e.g.,* via a shared Federation Object Model – FOM). With the advent of distributed simulation and, more recently, the potential "mix and match" capabilities of the HLA and the Federation Development and Execution Process (FEDEP) Model to support relatively arbitrary collections of simulation federates, establishing a common "terrain view" among multiple federates is becoming an increasingly important task.

Current terrain database generation processes produce customized data sets that aren't easily shared. Despite the increasing use of SEDRIS technologies, the process of finding "common ground" across a federation, in terms of terrain content, remains a non-trivial challenge – this involves establishing interoperability pre-runtime through the sharing of common terrain databases, or during execution through shared models of dynamic terrain. Sharing terrain data dictionaries and data models are critical preconditions to establishing terrain interoperability. A longer-term view has these program specific data models being established as profiles of Reference EDMs based on common EDM language and structure for each environmental sub-domain or functional area (e.g., Ground Combat, Air Combat, etc.).

Given these M&S trends, it is clear that we need to move beyond the essentially hand-crafted terrain data modeling approaches used in current systems like STOW and CCTT. What is required is a rational approach to terrain data model *design* that can be used to help define the basis for terrain data production requirements, terrain integration constraints and expectations, SEDRIS transmittal contents, and runtime terrain data use.

EVOLUTIONARY APPROACHES

JSIMS, STOW and JWARS Terrain Common Data Model (TCDM)

The Joint Simulation System (JSIMS) Synthetic Natural Environment (SNE) (including the Army component, WARSIM 2000), the DARPA STOW Worldwide Terrain Database generation effort [5, 6], and the Joint Warfighting Simulation (JWARS) SNE have jointly defined a TCDM spanning the *low*- through *medium*-resolution simulation requirements spectrum – including explicit provisions for extensibility to meet high-resolution requirements. Known as the JSIMS TCDM, it is physically realized differently in each of these simulations, but the process of populating a compliant terrain database (TDB) from standard DoD data products is shared. SEDRIS transmittals of these terrain databases are also easily sharable, as a consistent semantic and underlying design philosophy has been adopted that increases the likelihood of "correctness of use". In particular, the requirements of both virtual and constructive simulations have been taken into account (including both platform- and aggregate-level simulations).

Customers of the JSIMS TCDM. Customers included system requirements analysts, military model developers, SNE software developers, SNE data providers, and potential new federates with whom one of these simulation systems may need to interoperate.

JSIMS TCDM Development Strategy. The strategy for developing the TCDM was to:

- Define a *runtime* data model, which
- Was extended to become *common* with the TDB generation system, which
- Was initially scoped to the *terrain* (but to be later extended to the full SNE), and
- Would be subsequently evolved to achieve commonality with future WARSIM (and JSIMS) runtime federates such as OneSAF and CCTT.
- The resulting TCDM includes both static and *dynamic* terrain environmental data – the later being specified either as part of scenario tailoring prior to exercise initialization ("ExInit"), or as a result of the execution of warfighter models at runtime.

Military Functional Uses. The content of the JSIMS SNE is dictated by the military models incorporated in JSIMS and what information they need to know about (or modify in) the physical environment. While one can develop a haphazard "laundry list" of individual terrain elements to be included, this tends to result in an inconsistent characterization of the terrain that can confuse developers of military models (and the resulting software). The resulting data model tends to suffer from dependence on the TDB instance being initially developed, ending up skewed by "clearly importance" terrain features with potentially significant loss in generality. Subsequent TDBs (particularly in different geomorphologic and climatic zones) generally require extensions to the "laundry list" to correct overlooked or incompletely characterized terrain data elements.

The approach used in JSIMS SNE development was to first identify the primary ways in which the physical environment influences military operations, as they will be modeled in the simulation; then to identify the varied terrain conditions which contribute to each influence; and finally to identify specific phenomena/features, attributes, and relationships required to be populated to describe those environmental conditions.

The result not only ensures more complete consideration of the effects of environmental phenomena, but also leads to a more consistent characterization of those effects in terms of spatial and non-spatial terrain element descriptions. A clear delineation of these consistencies, and how they are expected to couple to (and influence) military models, leads to both better use by military model developers and assurance that the necessary elaborations of the available, but incompletely specified, environmental requirements are well founded. Finally, it eases the job of the Subject Matter Expert (SME) since related "families" of terrain elements can be considered and analyzed in the most efficient manner – from the perspective of their effect on military operations.

We have divided military operations, as they are influenced by environmental conditions, into 10 functional uses:

- Cross-country ground unit/vehicle mobility
- On-road ground unit/vehicle mobility
- Air unit/vehicle mobility
- Maritime water unit/vehicle mobility
- Riverine water unit/vehicle mobility
- Intervisibility
- Targeting and battle damage assessment (BDA)
- Combat engineering
- Civilian environment
- Logistics

Explicitly associated with each feature are one or more functional uses.

Implementation. The TCDM was realized as a Microsoft Access® 97 database which contains the data model itself, and a Microsoft Word® document which contains ancillary information, the most important of which is the description of the detailed rationale for design decisions.

OneSAF Testbed, CCTT

The framework underlying the JSIMS TCDM is being extended to support features, attributes, and linkages to military functional uses supporting the OneSAF Testbed and CCTT [7]. The resulting data model assumes an enhancement to the OneSAF Testbed runtime database format (CTDB) for a generic ability to encode the full classification and attribution of features.

Terrain Scenario Generation and Archiving (TSGA)

The DMSO sponsored TSGA project is developing processes for the fully automated production of low-resolution terrain databases anywhere in the world. Feature data incorporated in these TDBs is primarily derived from VMAP Level 0 (1:1,000,000 source). To avoid leaving potentially valuable feature data “on the cutting room floor”, the JSIMS TCDM was extended to include the additional features shown in Table 1. Additional attributes were added to the data model as well.

Table 1. Features and Attributes Added to JSIMS TCDM to Support Use of All VMAP 0

Classification Code	Name	Type	Attribute Codes
AI030	Camp	Point	NAM_, TXT
AL025	Cairn	Point	NAM_, TXT_
AL130	US-Monument	Point	NAM_, TXT_
BH090	Land Subject to Inundation	Area	HYC_
BH180	Waterfall	Point	
BJ065	Ice Shelf	Area	NAM_
CA030	Spot Elevation	Point	ACC_, ELA_, ZV2
CA035	Inland Water Elevation	Point	ACC_, ELA_, ZV2

Marine Corps Urban Warrior

The MC Urban Warrior environmental requirements were previously documented by the USA ERDC/TEC using Microsoft Excel® spreadsheets. Subsequently, two distinct data models were developed and incorporated into the Common Data Model Framework, described below. The first model provides extensive feature and attribute detail and includes a comparison to Digital Topographic Data (DTOP). It provides no indication as to feature (geometric) type. Such information is highly desirable when assessing a terrain data model’s capability to provide needed detail for military models (*e.g.,* the ability of a vehicle to travel along a line of communication), as well as when comparing the terrain data model to source data products. The second model identifies features and attributes and identifies the geometric feature type of each feature.

The ease with which review and analysis of these data models was conducted demonstrated that significant advantages are to be gained by representing environmental data models using relational database technology.

Ocean and Atmosphere Data Model

The data modeling efforts described above have focused on terrain. However, the ocean and atmosphere are natural environment domains of equal or greater importance than terrain in many military M&S applications. DMSO and STRICOM have undertaken an effort to apply the common data modeling framework underlying the TCDM and develop EDMs for the Ocean and Atmosphere. The program, called Ocean and Atmosphere Requirements and Data Modeling (OARDM), has two goals. The first is to expand the framework established by the previous terrain-oriented data modeling efforts in order to meet the unique representation requirements of the atmosphere and ocean. The second is to populate this framework with data models for representative simulations and establish a baseline for follow-on development of environmental sub-domain EDMs for the Ocean and Atmosphere.

Framework extension. The atmosphere and ocean environmental domains differ in a number of ways from terrain. For example, attributes in these domains often are physically interrelated, whereas the attributes of a terrain feature generally have more limited physical coupling. For instance, the temperature, dew point, and humidity of a point in the atmosphere are strongly coupled through basic physics, whereas the length and width attributes of a terrain feature have, in general, no necessary pre-defined relationship. The current common data modeling framework is being extended to support these types of representations. The ultimate goal is the production of a general Environmental Data Model – a framework that includes all natural environment domains (terrain, ocean, atmosphere, and space).

Populating the framework. The second goal of the OARDM effort is to populate the extended framework with data models for specific simulations. The current effort is developing data models for three existing modeling and simulation programs that span a wide range of resolutions and applications. These are JWARS, JSIMS, and the DMSO sponsored Environment Federation (EnviroFed). JWARS supports campaign level analysis for the Quadrennial Defense Review. JSIMS supports command and staff training. EnviroFed is a constructive simulation federation that supports a platform level of resolution typical of virtual simulators. Further work is expected to add data models supporting C^4ISR systems. The common data model that emerges from this growing collection of atmosphere and ocean data models for varied systems should give atmospheric and ocean data providers valuable insight into the true requirements of these systems. This should ultimately expedite the widespread availability of suitable data to support these systems and M&S in general.

AN ENVIRONMENTAL COMMON DATA MODEL FRAMEWORK

Across the breadth of M&S, natural environment data requirements can vary dramatically. Lacking a systematic way to compare requirements between different applications can lead to limited interoperability. When defining a data model for natural environments we seek to simultaneously address the needs of M&S interoperability, specific program requirements, Subject Matter Expert (SME) input, and simulation system behavior requirements, all with respect to available source data. These are lofty goals, but doable and proven in the JSIMS TCDM development.

The Common Data Model Framework (CDMF) extends program specific data modeling to address the needs of multiple programs (the "system of systems" problem). Given a set of specific framework directives, a program's data model can be captured in the CDMF and compared with other environmental data models and available source data. The CDMF provides mechanisms by which data models may be reviewed, evaluated, enhanced and validated.

The foundation of the CDMF is a relational database, currently a Microsoft Access® 97 database with associated macros, queries, reports and associated software and documentation. For an environmental data model to be captured and analyzed in the CDMF, it must minimally (1) identify the supported features, and (2) identify the supported feature attribute combinations.

Features are identified by a combination of Feature Classification Code and Feature Type (referred to as a Feature Identification (ID)). Attributes are identified by an associated Feature ID and an Attribute Code. To add a data model to the CDMF, at least the three following basic tables are needed. They must exist in a standalone database whose tables can be linked into the CDMF database.

Table	Description
Content Description	Provides the lineage of the data model, data model history and version information.
Feature Usage	Lists the features comprising the data model
Attribute Usage	Lists the attributes employed by the data model identifying those provided via source data attributes and those that are derived.

Figure 1 illustrates the relationship of the CDMF database/tables to program/product databases. Using this information, the CDMF can be used to derive the information necessary to perform comparisons and analyses.

Data Model Analysis

Source data analysis within the CDMF requires identification, description and comparison of available source data products. This information is currently housed in a separate (from the data models) Microsoft Access® 97 database and accessed through table links. Source data product types currently supported are: VMAP Level 0, VMAP Level 1, Foundation Feature Data (FFD), DTOP Levels 1 – 5, Digital Nautical Chart (DNC), Littoral Warfare Data (LWD), and Tactical Ocean Data (TOD). CDMF analysis provides identification of specific features and/or attributes, and the source data products from which they can be obtained. Figure 2, *e.g.,* shows which data products support the Mine (AA010) feature and its attributes. It was generated by a CDMF report.

Program specific environmental data models can be compared in a similar manner. To date, the CDMF has been used to analyze several terrain data models including the pair of MC Urban Warrior data models, the JSIMS/ WARSIM Terrain Common Data Model and a Ft. Knox/MOUT DTOP data model. Figure 3 illustrates the data model attributes required for each of these four programs for the Mine feature. Summary information can also be easily generated, *e.g.*, see Figure 4.

EDM DEVELOPMENT PROCESS

The development of an environmental data model begins during the requirements analysis phase of a program. The formal requirements must be reviewed from two perspectives – that of identifying requirements explicitly imposed on the simulated environment (*e.g.,* “the simulated environment shall include objects representative of urban areas”) (see Reference [8]), and identifying requirements implicitly imposed on the simulated environment. Implicit requirements can be considered derived requirements having their source in requirements explicitly tied to simulation elements that in some way use environmental information. An example might be a requirement for a simulated vehicle to respond to the effects of a changing terrain surface. For this example, further analysis would be needed to identify the types of terrain the actual vehicle is able to traverse (and those types found in the regions to be included in the database), the surface characteristics affecting traversal (*e.g.,* soil type, moisture content), and the required resolution of the vehicle model to be developed.

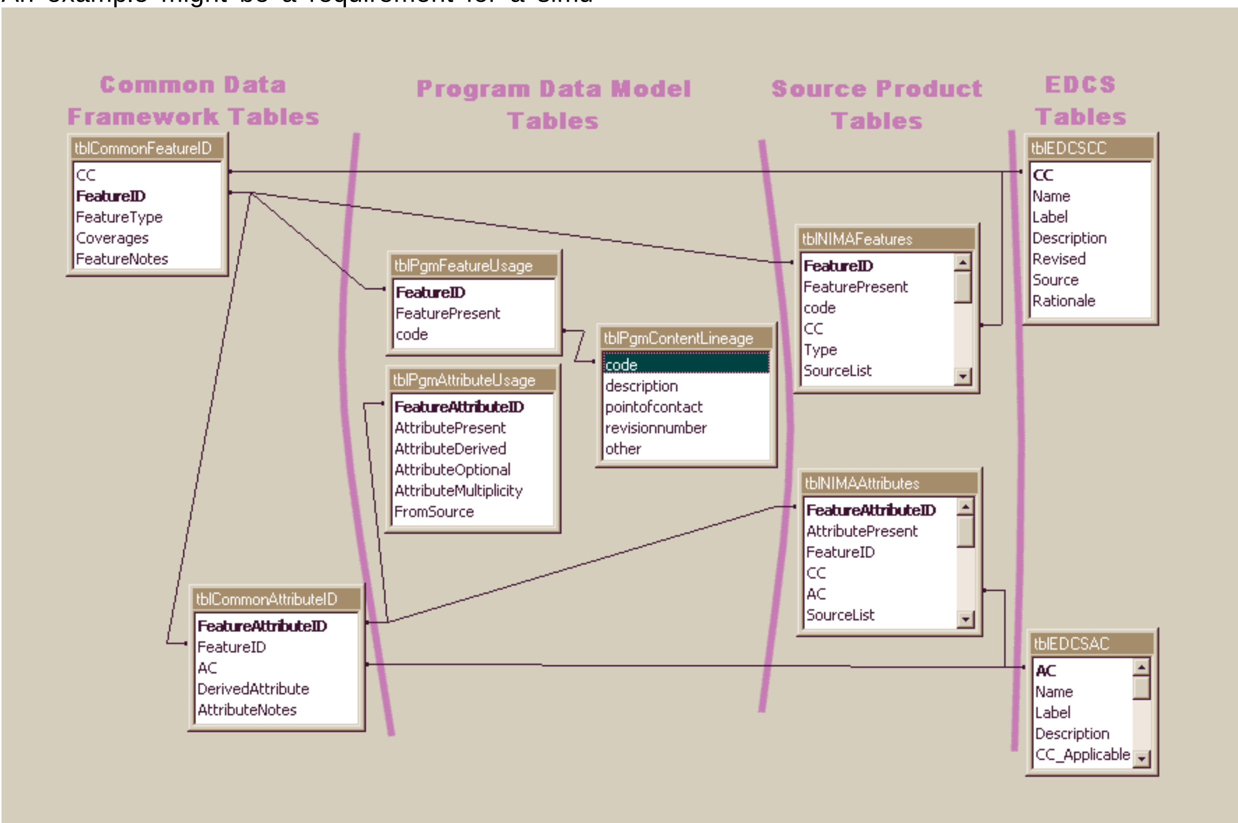

Figure 1. Tables in the CDMF are related to tables from multiple program data models and multiple source product tables.

Source Product Report

Feature Name	Classification/Type	Description
Mine	AA010 / A	An excavation made in the Earth for the purpose of extracting natural deposits. (See also AQ090.)

	Attribute Code	DTOP	VMAP0	VMAP1	FFD	DNC1	LWD	TOD
		☑	☑	☑	☐	☑	☑	☑
Accuracy Category	ACC_	☐	☐	☐	☐	☐	☑	☐
Area with Greater Than 1 Meter Squared Resolution	ARE_	☐	☐	☐	☐	☐	☑	☐
Conspicuous Category	COC_	☐	☐	☐	☐	☐	☑	☐
Certainty of Existence	COE_	☐	☐	☐	☐	☐	☑	☐
Depth Below Surface Level	DEP_	☐	☐	☐	☐	☐	☑	☐
Existence Category	EXS_	☑	☐	☑	☐	☐	☑	☐
Height Above Surface Level	HGT_	☐	☐	☐	☐	☐	☑	☐
Length / Diameter	LEN_	☐	☐	☐	☐	☐	☑	☐
Mining Category	MIN_	☑	☑	☑	☐	☐	☑	☐
Name	NAM_	☑	☐	☑	☐	☐	☑	☐
Product Category	PRO_	☑	☐	☑	☐	☐	☑	☐
Text Attribute	TXT_	☐	☐	☐	☐	☐	☑	☐
Width	WID_	☐	☐	☐	☐	☐	☑	☐

Figure 2. Source Product Report

Feature and Attribute Comparison

AA010 Legend for Program Requirements: X Required; O Optional; d Derived; M Multiple; MO Multiple+Optional; dO Derived+Optional AA010

CC	Feature Type	CC Name	CC Description
AA010	Area	Mine	An excavation made in the Earth for the purpose of extracting natural deposits. (See also AQ090.)

	Program Requirements					Attributes		Found in Source Product
		☑	☑	☑	☑			
	Derived	JSIM	KNX	UW2	UW	AC	AC Name	DNC DTOP LWD TOD VMAP0 VMAP1
1	☐			X	X	ACC_	Accuracy Category	LWD
2	☐			X	X	ARA_	Area Coverage Attribute	None
3	☑	d				ARE_	Area with Greater Than 1 Meter Squared Resolution	LWD
4	☐				X	ARH_	Area Coverage Attribute - Hectares	None
5	☐			X	X	COC_	Conspicuous Category	LWD
6	☐			X	X	COE_	Certainty of Existence	LWD
7	☐					DEP_	Depth Below Surface Level	LWD
8	☐	X				DGEN	Damage, General	None
9	☐		X	X	X	EXS_	Existence Category	DTOP LWD VMAP1
10	☐			X		HGT_	Height Above Surface Level	LWD
11	☐			X		LEN_	Length / Diameter	LWD

Figure 3. Feature and Attribute Comparisons

Summary of Attribute and Source Analysis

Program Code	Total Attributes	Attributes Not Required in Source	Attributes for which Source Required	Attributes Found in Source	Attributes Not Found in Source	DNC	DTOP	FFD	LWD	TOD	VMAP0	VMAP1
						Distribution of Attributes Found in Source Products						
JSIM	1516	730	699	355	344	59	139	53	424	60	31	101
KNX	728	0	728	662	66	77	626	116	585	80	31	176
UW	8672	0	8672	3997	4675	600	684	162	3708	611	101	334
UW2	4338	0	4338	4087	251	498	652	123	4087	543	83	254

Figure 4. Summary Analysis

Key to the formalization of any requirements baseline is interaction among the various simulation system development groups and with appropriate SMEs. Depending on the complexity of the simulation and the level of interaction among simulation elements, this may require several meetings that begin in the requirements analysis phase and continue throughout the development phases. The primary goal of these meetings is to identify features, feature characteristics (attributes) and feature relationships that support the simulation elements, meet specified requirements and that can be supported (*e.g.,* is there a source for the needed information?). Additionally, the ultimate use of the simulation system must be analyzed, most often through use cases. The products of such meetings should include not only the environmental information and relationships, but the rationale for all decisions made. This rationale should include references to validated resources and documents as appropriate.

Once the environmental objects, their attributes and relationships have been identified, this information can be formalized into an environmental data model. In a sense, the development of the data model is a distillation of the information obtained from the various developmental groups, SMEs, the requirements, and the available use cases. This distillation must result in a final product that a) meets the specified environmental requirements, b) allows the simulation elements to meet their requirements (from the perspective of their interactions with the environment), and c) does this in such a way as to be concise, complete and unambiguous. The distillation process itself must take into consideration how each simulation element uses the data and the operational conditions under which the data is to be used. For example, if two simulation elements require the same information but in different units of measure, is there an advantage over using one unit versus another? One consideration might be the performance requirements for each of the simulation elements using the data. If one uses the information in the background or off-line and the other uses it in real-time, it is probably best to store the data in the units of measure required by the real-time simulation element. Another item to be considered during the distillation process is data resolution/scale. Sufficient information may need to be provided in the data model to allow one simulation element to *view* the environment at one scale, and another at a different scale – yet both scales must result in the same interpretation of the object (*i.e.,* correlation).

An additional aspect of this distillation process may include (depending on program-specific requirements) a comparison of the data model to other/existing data models. This may be desirable in that it could serve to identify missing/incomplete information and further the extension of a particular data model. For example, the development of the JSIMS TCDM included agreement that features/attributes added to the model, but not found in the EDCS, would be submitted for inclusion in the EDCS standard.

RELATED EFFORTS

Related efforts are underway in several arenas to identify or extend various environmental data models. Three such efforts are the "One Step Process", the Objective OneSAF EDM, and the Army's Functional Description of the Battlespace.

Army Model and Simulation Office IPT – the "One Step Process"

The U.S. Army, led by the Army Model and Simulation Office (AMSO) and the Environmental Database Integrated Product Team (EDB IPT), has recently begun developing the concept of a "One Step Process" for environmental database production for joint use by the M&S and C^4ISR communities. The driving force is the desire to reduce the time and the cost of interoperable database development capable of meeting the diversity of user requirements. The database conceptual model requires end-to-end correlation and validation from diverse source data development, through the development of a SEDRIS Transmittal Format of a master data set, to the compilation and production of application-specific databases. In examining potential methods of economizing this complex process, the need for a source data framework that encompasses all of the requirements of both the M&S and the C^4ISR communities has been identified as an important piece of the "One Step Process" development. Imagine for a moment if all environmental source data for all potential users could be produced to a standard "framework" thereby saving (through reuse) a large amount of the manually intensive rework performed today by database developers answering the diverse requirements of the varied users. The STRICOM Synthetic Natural Environment Science and Technology Objective (SNE STO) has this vision as its goal and objective. Through the collaborative efforts of the STRICOM SNE STO, an Army Model Improvement Program (AMIP) proposal funded through AMSO, and a series of AMSO funded

Simulation Technology (SIMTECH) proposals, the Army has begun taking the first steps toward achieving the vision of a "One Step Process".

Objective OneSAF

The production of environmental databases is integral to most of STRICOM's simulation and simulator development programs. In the past the specification of requirements for the environment has been an unstructured *ad hoc* process of balancing user requirements against processing and fiscal constraints. As the complexity of environmental data has increased, this process has become unmanageable. For the OneSAF Objective System (OOS) development, which must satisfy the requirements of a very broad spectrum of users, a more structured process for requirements analysis, and process design and development, will be adopted.

An Operational Requirements Document (ORD) and a Technical Requirements Document (TRD) have been written for the OOS, defining the environmental requirements at a very high level. The CDMF process offers STRICOM the opportunity to capture the range of OneSAF environmental requirements in a common, consistent framework at a level of detail and with relationships defined that developers need for implementation. The OneSAF EDM will be developed early in the system lifecycle to capture user requirements for environmental data. Data elements and their relationships will be clearly defined and linked to training tasks and to source data through the CDMF. The design of the EDB development process will be derived from the EDM to enable OneSAF to have a consistent, repeatable EDB generation process. Once the environmental database generation process is in place, a OneSAF user will be able to identify the data elements required to meet his specific training requirements, locate source data, and produce an environmental database through a well-defined, unambiguous process.

In WARSIM, software processes and models are data driven and so the JSIMS TCDM forms the cornerstone for development of the runtime software. The JSIMS TCDM is used to produce software configuration files to drive the Terrain Data Fusion System (TDFS) which produces the data set used to compile the runtime databases. Many of the runtime software modules are similarly data-driven by JSIMS TCDM configuration files. This data-driven approach ensures that software functionality can be adjusted quickly and efficiently without code modifications, and ensures that databases and software models are consistent with each other and with documentation (the JSIMS TCDM).

The OOS must interoperate with WARSIM and the JSIMS family of simulations. The OOS EDM will permit OneSAF to leverage the WARSIM data-driven approach reducing software development cost and risk. Since the OOS EDM builds on the structure as the JSIMS TCDM, there will be a solid foundation for interoperability.

MAINTENANCE, CONFIGURATION MANAGEMENT, OWNERSHIP, AND DISTRIBUTION

The U.S. Army is considering the use of the CDMF as a "baseline" for development of a family of interoperable Terrain Data Models. With increasing breadth of use of the CDMF, it is important to tackle the issues of maintenance, configuration management, ownership, and distribution. Obviously the key concern of PM WARSIM, who developed the original JSIMS TCDM, is the guarantee that any further development for the broader usage across the total Army M&S and C^4ISR communities continues to maintain a fully separable (and interoperable) model within the framework for WARSIM usage. Representatives from the WARSIM Program, the STRICOM SNE STO Program, the OneSAF Testbed, the OneSAF Objective System, AMSO, and DMSO have drafted a Memorandum of Understanding (MOU) that addresses these issues.

As the CDMF is extended to other simulation applications, and ultimately to the development for total Army usage (and perhaps eventually Joint) across all three domains (training, analysis, and acquisition) of M&S plus C^4ISR, these issues of maintenance, configuration management, ownership, and distribution will require a formal arrangement. It is anticipated that a configuration management board will be developed with appropriate representation from all potential stakeholders. The key to the success of the development of a CDMF for the Army, and perhaps eventually for the Joint community, is to maintain a design and development approach that allows for fully separable (but interoperable) data models for usage in individual M&S and C^4ISR systems while supporting ready distribution throughout the U.S. DoD and its contractors.

FUTURE DIRECTIONS

The Objective EDM

The long-term objective is to develop a general Environmental Data Model that captures the broad collection of requirements for systems using M&S technology. This EDM would have components for each natural environment sub-domain (terrain, atmosphere, ocean, and space). The resulting logical data model baseline will use Environmental Data Coding Specification (EDCS) labels, definitions, and codes. It will be the source for lower-level physical EDM implementations supporting various user community and program specific implementations. It is envisioned that a registry process will be established for maintaining both the baseline EDM and profiles derived from it.

This EDM organizational scheme will enable interoperability though common language and notation. When coupled with the supporting CDMF, it will provide users a common view of the full environmental content of networked simulations not currently available. Additionally, this structure can be used to better define and expand the environmental conditions in the Universal Joint Task List (UJTL) and other supporting descriptions of the environmental mission space.

Leveraging the UCDM

We have recently analyzed the NIMA UCDM [1]. In development since 1993, it represents the collaborative development by teams from NIMA, intelligence and other organizations. Using IDEF1X methodology, its modeling components are entities, attributes, and relationships. The UCDM explicitly captures relationship information which the current CDMF only captures through a mixture of explicit (coverages) and implicit (rationale) mechanisms. The advantage of the UCDM structure over the current CDMF approach is its ability to explicitly model relationships in two ways: first as a labeled associations between entities (*e.g., may contain*, *supports*, *may be crossed by,* etc.), and second, by the creation of relationship entities (*e.g.,* a ROAD entity *may cross a* ROAD-STREAM entity, and a STREAM entity *may be crossed by a* ROAD-STREAM entity; a ROAD entity *leads to a* FERRY-ROAD-ASSOCIATION entity, and a FERRY-SITE entity *is connected to a* FERRY-ROAD-ASSOCIATION).

Reference [9] develops a taxonomy of the JSIMS TCDM features for the purpose of more easily identifying incorrect feature relationships. In the associated presentation, an image of Hoover Dam is shown and the following questions posed: *A major roadway travels across the top of the Dam: Should it be classified along with bridges or roadways? Should all dams be grouped with bridges? Should every bridge be classified as a dam?* The UCDM appears to handle this well: it defines a ROAD-DAM entity with the relationship that an IMPROVED-ROAD entity *may be supported by a* ROAD-DAM entity.

Unfortunately the UCDM currently only captures this information using commercial proprietary tools (ERWin®) and formats, and not in the more open form of relational tables (although this certainly could be accomplished). In Version 4, the UCDM development team has committed to defining mappings between the UCDM Data Dictionary and FACC and between UCDM and the NIMA FACC Profile. Once these mappings have been established and the UCDM relationships are captured in a relational model, it may be possible to link the UCDM into the CDMF to support quantitative analysis between the UCDM and other program-specific data models.

Means of Leveraging Requirements on other System Elements

Each environmental object can affect the simulation system in multiple ways. For example, a church is an impediment to mobility by vehicles, it restricts line of sight, and is important for collateral damage avoidance. A pipeline is an obstacle to mobility and carries oil or gas, which may be important if the system is simulating logistics. The Environmental Data Model is a logical place to maintain explicit (though often derived) requirements about how each environmental object should affect other system elements. This explicit linkage, added to support the JSIMS TCDM, will be extended for the Objective OneSAF.

CONCLUSIONS AND SUMMARY

Environmental data models are important to specify during the system requirements analysis and development phase of a simulation program. These should be formal data models, based on the EDCS, which completely and unambiguously describe the potential content of the physical environment. An approach that develops a general Environmental Data Model, with associated sub-domain data models, further scoped to a specific user community through reference EDMs and program-specific EDMs will create the opportunity for subsequent interoperability. A Common Data Model Framework has been developed utilizing relational database technology which will serve as a repository for multiple data models, including both the JSIMS TCDM and the data model being developed for the Objective OneSAF.

REFERENCES

[1] USIGS-CDM-C, November 23, 1999; http://164.214.2.59/sandi/datamodel/ucdm/index.html.

[2] P. Birkel *et al.*, "The Terrain Common Data Model (TCDM): a Joint Effort of JSIMS, STOW, and JWARS", *Proc. 8th Computer Generated Forces & Behavioral Representation*, paper 8TH-CGF-004, May 1999.

[3] http://www.digest.org/.

[4] R. Richbourg *et al.*, "Standardizing the codification of environmental objects: the Environmental Data Coding Specification", *Proc. Simulation Interoperability Workshop,* paper 00F-SIW-071, September 2000.

[5] P. Birkel *et al.*, "Pushing the Envelope Toward a Common Process for the Generation of Terrain Data Bases across Federations", *Proc. Simulation Interoperability Workshop,* paper 99S-SIW-016, March 1999.

[6] D. Miller *et al.*, "The STOW World Wide Terrain Data Base" *Proc. Simulation Interoperability Workshop,* paper 99F-SIW-042, September, 1999.

[7] A. Janett *et al.*, "Extending the JSIMS Terrain Common Data Model to Support Virtual Simulations", *Proc. Simulation Interoperability Workshop,* paper 00S-SIW-112, March 2000.

[8] P. Birkel, "SNE Conceptual Reference Model", *Proc. Simulation Interoperability Workshop,* paper 98F-SIW-018, Sept., 1998.

[9] R. Richbourg and T. Stone, "Searching for Functional Equivalence Classes in Environmental Data", *Proc. Simulation Interoperability Workshop,* paper 99F-SIW-108, Sept. 1999.