

A Comparison of the Land C2 Information Exchange Data Model And the WARSIM Object Model

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ABSTRACT: *This paper presents the results of a case study in assessment of data alignment between C4I and M&S models. In the C4I domain the model is NATO's Land C2 Information Exchange Data Model (LC2IEDM). The LC2IEDM is a relational model, and is an international standard for tactical databases. In the M&S domain, the model is from the Warfighter's Simulation 2000 (WARSIM), the U.S. Army's next-generation command and control training environment. It will support training from battalion through theater level. It is designed as a federate, publishing classes and types through the Joint Simulation System (JSIMS), to facilitate its use in joint and combined scenarios. The paper shows that, although there is substantial overlap in the data modeled by the LC2IEDM and WARSIM, some data areas have significant problems in mutual coverage and compatibility. The LC2IEDM does not adequately capture some of the dynamic data that is necessary in a simulation, and the WARSIM model cannot fully describe the real world as the LC2IEDM expects. This paper summarizes results of the data alignment study and makes specific recommendations for changes to the LC2IEDM and to WARSIM that would improve their interoperability. Partially in recognition of misalignments identified in this and other studies, a major initiative has been started to develop an ArmyC4I-M&S Reference Object Model that would support Army data requirements from M&S as well as C4I systems.*

1 Introduction

1.1 Purpose

The purpose of this paper is to describe a recent case study assessing common data/object model alignment between two prominent models from the C4I and the M&S domains: NATO's Land C2 Information Exchange Data Model (LC2IEDM) [10] and the Warfighter's Simulation 2000 (WARSIM). This assessment reveals the status of data alignment between representative C4I and M&S models, identifies changes needed to bring these models into better alignment, and provides a basis for proceeding to develop a common reference object model

capturing both C4I and M&S data requirements to improve future interoperability between C4I and M&S systems.

1.2 Background

Interoperability between C4I and M&S systems can be enhanced by the use of well-aligned representations of data in both types of systems [6]. Data from different systems is well aligned to the extent that it has a common semantics and (to some extent) syntax, i.e., it covers the same type of information using similar data elements. Such alignment facilitates the movement of data between systems, minimizing the need for costly translation systems and their attendant risks of errors. A first step in promoting interoperability through data alignment is an

assessment of the current status of alignment between representative data models.

A previous study [14],[15] assessed data alignment between the “Standard Objects” of the Army’s Modeling and Simulation Object Model Standards Category (OMSC) [6] and the Army Integrated Core Data Model (AICDM) [1]. Because the OMSC is a high-level architectural model, it was considered important to examine C4I/M&S data alignment using a more detailed representative M&S model. This paper presents a summary of results of an alignment assessment between the LC2IEDM and WARSIM. The full study contains complete details of the data elements mapped as well as a mapping to the Joint Common Database [9]. The full study will be available as [4].

1.3 Paper Organization

This paper begins with overviews of the WARSIM and LC2IEDM models. Then it presents a brief description of the alignment assessment methods that were used, whose details appear in the full study report [4]. Then the results of the assessment study are presented first from the perspective of mapping WARSIM elements into the LC2IEDM, and then the reverse. These results are presented for three main areas of the models: unit, equipment, and environment. Finally, recommendations are made for adjusting these models to promote interoperability.

2 Overview of WARSIM Models

2.1 WARSIM

The Warfighter’s Simulation 2000 (WARSIM) will provide simulation tools to Army leaders that they can use to create realistic operational conditions for education, training, and mission rehearsal to meet Title X requirements. The program objectives include supporting Total Army and Joint Force events from Battalion through echelons above Corps in scenarios from across the operational continuum while reducing the resources required to prepare, execute, and assess simulation events. WARSIM 2000 will support real-time battle command training events such as seminars, Command Post Exercises (CPXs) and Battle Command Training Program (BCTP) events in all type units and schools.

The best documentation of current WARSIM battlefield objects and attributes can be found in the WARSIM managed parts of the Joint Simulation System (JSIMS) Federated Object Model (FOM). Thus, we used WARSIM managed elements in the JSIMS FOM (Version 6.0) [3] as the primary basis for our assessment of data alignment between WARSIM and the LC2IEDM. However, because such FOMs are designed to document dynamic data that is exchanged by simulations during an exercise, the JSIMS

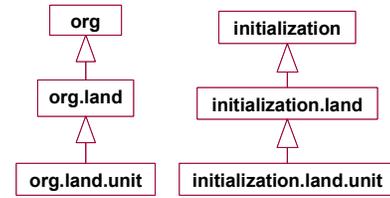


Figure 1. Unit Area of WARSIM

FOM does not include the relevant static terrain data. Thus, we also included the JSIMS Terrain Common Data Model (TCDM) [8] in our alignment assessment.

2.2 JSIMS FOM

JSIMS is a federation of many different simulations, including WARSIM for the Army, the National Air Space Model (NASM) for the Air Force, and Maritime for the Navy [3]. In order to focus on WARSIM related elements, this alignment assessment is restricted to those object classes (and their attributes) in the JSIMS FOM for which WARSIM has management responsibility. Available resources were insufficient to extend this analysis to all of the object classes to which WARSIM subscribes, or to any of the interaction classes that have WARSIM involvement.

To enable assessment in different modeling areas, we divided the analysis space into 4 main areas: Unit, Equipment, Environment, and C4I. The Unit area comprises the classes and inheritance relations illustrated in Figure 1. The Equipment area comprises the classes and inheritance relations in Figure 2. Each class has zero or more attributes. An attribute may be atomic (e.g., an integer) or a complex data type (e.g., a 3-d coordinate).

There is considerable overlap between the Unit area and the Equipment area classes. This is because all equipment information on platforms is stored in attributes of subclasses of the org class (e.g., in org.land.supply_cache and org.land.equip_group) in this model.

The only WARSIM managed Environment area class in the JSIMS FOM is minefield.land, because it is the only dynamic part of the terrain. Other terrain elements from the TCDM are discussed in the next section.

The C4I area consists of C4I initialization classes and “C2_artifacts” classes. They were not included in the assessment because they contain only data peculiar to specific C4I system interfaces and do not contain battlefield information.

2.3 Terrain Common Data Model (TCDM)

The TCDM describes the terrain component of the Joint Simulation System (JSIMS) Synthetic Natural Environment (SNE). The TCDM includes features that will be represented in the JSIMS Terrain Database. This study used TCDM Revision 1.2a [8].

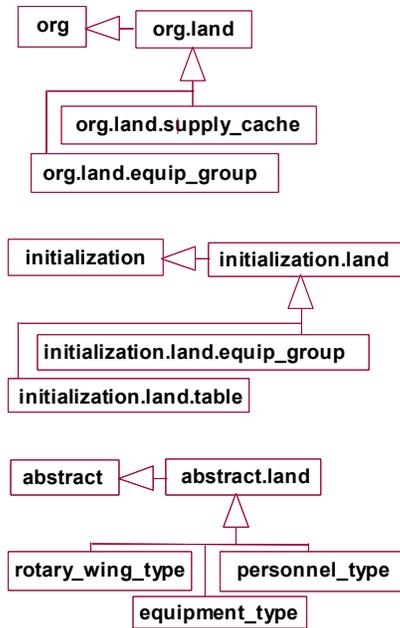


Figure 2. Equipment Area of WARSIM

The TCDM is a logical data model that addresses both low- and medium-resolution simulation requirements. It was designed to be extensible to accommodate high-resolution requirements. The TCDM supports both virtual and constructive simulations at the platform and aggregate levels of resolution. The TCDM was built on the Environmental Data Coding Specification (EDCS) [10], and will be used by JSIMS to specify terrain database content requirements, and for the development of the terrain databases.

The design of the TCDM was driven by the needs of the warfighter and military modeler to represent concepts of interest, as well as a requirement for efficient runtime reasoning about the SNE in the context of a military model. These needs implied organizational and representational requirements for the data model.

Trade-off studies based on model resolution, use, consistency, and performance led to the decision to use feature representations rather than geometric representations in the data model. The resulting TCDM is organized into thematic layers, called coverages. Coverages align with how subsets of terrain features would be represented and processed. Within each coverage the data model is flat (except for Surface Areas, which has four subcoverages). The coverages and subcoverages are:

- Surface Areas
 - Physiography
 - Vegetation
 - Urban
 - Water
- Point Culture

- Linear and Point Hydrography
- Linear and Areal Terrain Obstacles
- Maritime Trafficability
- Linear Connectivity/Distribution
- Linear and Point Transportation
- Metadata
- Geotile Reference
- Administrative Boundaries
- Battlefield Elements

The Geotile Reference coverage is used only for database generation. It contains elevation profiles along the Geotile Reference System (GTRS) geotile boundaries. The Metadata coverage contains data type source lineage information.

Within a coverage most features share a consistent attribute set. The TCDM specifies the data type for each attribute, the range of allowable values, and in some cases, a default value for an attribute. For enumerated data types a complete set of enumerations is provided.

3 Overview of the LC2IEDM

The version of the LC2IEDM used in this assessment corresponds to the release of 31 March 2000 by the Army Tactical Command and Control Information System (ATCCIS) group. It contains 149 entities, ten of which are independent: ACTION, CANDIDATE-TARGET-LIST, CAPABILITY, CONTEXT, LOCATION, OBJECT-ITEM, OBJECT-TYPE, REFERENCE, REPORTING-DATA, and RULE-OF-ENGAGEMENT. Figure 3 shows the high-level relationships among these entities. The supertype entity OBJECT-ITEM contains the 5 battlefield objects FACILITY, FEATURE, MATERIEL, ORGANISATION and PERSON, whereas the supertype entity OBJECT-TYPE provides the corresponding hierarchy for their classes, namely, FACILITY-TYPE, FEATURE-TYPE, MATERIEL-TYPE, ORGANISATION-TYPE and PERSON-TYPE.

3.1 Background

The LC2IEDM was developed by ATCCIS to support land C2 operations in a multinational environment for echelons to include Brigade, Corps and above. It therefore emphasizes the data that national armies would share under such conditions and purposely leaves out those details that may traditionally be handled by the national C2 systems, such as personnel-related information. The model also reflects the philosophy that planning documents must be boiled down to the specific actions contained therein, and mapped to WHO does the action, against WHOM, with WHAT, WHERE, and WHEN. In addition, the model permits the specification of contextual data via REPORTING-DATA, REFERENCE and CONTEXT.

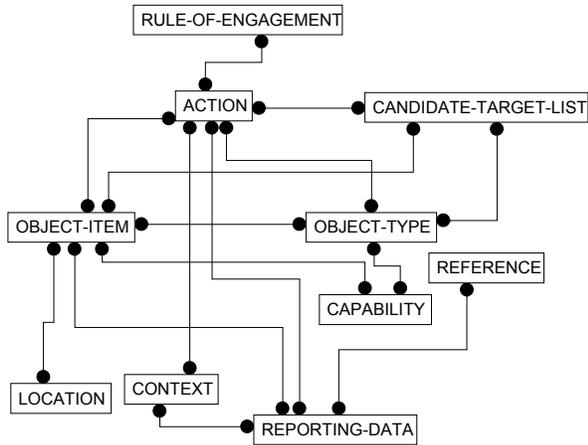


Figure 3. High-level Depiction of the LC2IEDM Independent Entities

3.2 Current Status of the LC2IEDM

The LC2IEDM is the fourth version of the original ATCCIS model, the Generic Hub (GH1). It is, therefore, also referred to as GH4. A fifth version (GH5) is currently under development and is expected to be released during 2002. The major changes with respect to GH4 are additional structures needed to support Operations Other than War, as well as extensions to interface with naval and air operations. NATO has adopted the LC2IEDM as the reference model for land C2. In the U.S. there are currently initiatives to use the model as the point of departure to support interoperability among services and agencies. The initial version of the Generic Hub (GH1) was used to develop DoD's C2 Core Data Model (C2CDM), now part of the DoD Data Architecture (DDA). The Army's Joint Common Database (JCDB), currently in version 5.0, was built from the C2CDM, and incorporated data structures from GH3, as well as from other Army information systems.

4 Alignment

4.1 Alignment Methodology Overview

Determining the extent of alignment between WARSIM and the LC2IEDM requires a more precise definition of what alignment means. Intuitively, WARSIM and the LC2IEDM are well aligned if they can model the same information. WARSIM is object-oriented, and an object has state; JSIMS expresses a state as a set of attributes. Therefore, WARSIM and the LC2IEDM are aligned to the degree that WARSIM and the LC2IEDM can express the same states for the same types of objects/entities.

We assess alignment using a four-level alignment level hierarchy, shown in Table 1. Each level focuses on a set of modeling elements from each model. Level 1 (Conceptual) is highest, meaning that alignment at Level 1 focuses on the most abstract elements in each model. At every level save the lowest, alignment is recursively defined, usually in terms of the next lowest level, and based on the type of modeling elements being assessed. For example, Entity-level elements are aggregates of attributes; to assess the alignment of a JSIMS class means to perform State-level assessments of each of its attributes.

This recursive definition also delineates an alignment assessment process. The analyst starts by distinguishing the highest-level abstractions to use in describing the models. Our division of the WARSIM models into the areas of Unit, Equipment, Environment, and C4I identifies the highest-level concepts for this assessment. The analyst then assesses the classes (or entities) involved in each such high level concept (Entity level), which he does by assessing the attributes of each class (State level); he assesses attributes by assessing the domain of each attribute (Value level if the attribute is an atomic value such as an integer or a string, and Entity level if the attribute is a complex data type).

The result of a Value-level alignment assessment is a percentage that measures the degree to which two domains overlap. The result of an alignment assessment is therefore a set of numbers, one for each Value-level assessment. We average these numbers to obtain an overall *degree of alignment*.

Table 1. The Four Levels of Alignment

Level	Participating Model Elements	
	WARSIM	LC2IEDM
1 CONCEPTUAL: Entities of user perception	Package (name, set of class/complex data type names, focal class name, associations)	View (name, set of entity names, focal entity name, relationships)
2 ENTITY: Aggregate elements of model	Class (name, description, set of attribute names) Complex data type (name, description, set of field names)	Entity (name, description, set of attribute names)
3 STATE: Descriptions of entity state	Attribute or field (name, data type, description)	Attribute (name, description, domain name)
4 VALUE: Descriptions of domains	Data Type (name, set of values)	Attribute Domain (name, set of values)

4.2 What's New About Alignment Assessment

The WARSIM-LC2IEDM alignment assessment has provided us the opportunity to extend the alignment methodology to cover areas unexplored in the AICDM/OMSC study [15]. This section briefly discusses some of the new areas. Complete details on the alignment methodology and its extensions are provided in [4].

4.2.1 Value-Level Alignment Assessments

Because the OMSC is a skeletal model, it seldom contains enough detail to make Value-level assessments feasible. The WARSIM/LC2IEDM assessment was therefore our first chance to gain extensive experience with Value-level assessments.

The degree of alignment for a Value-level assessment reflects the percent of overlapping values between two domains. What is specifically of interest depends on the direction of alignment. When assessing how well the LC2IEDM can model WARSIM values, the analyst is interested in knowing what percentage of values in a WARSIM domain can be modeled by an LC2IEDM domain, and vice versa.

WARSIM uses only eight distinct domains (integer, float, boolean, string, etc.) in the JSIMS FOM. A given attribute generally uses only a portion of the available values in a domain. Strings, for instance, may be up to $2^{31} - 1$ characters long, but we found no attributes whose length would ever approach that size. We accounted for these restrictions in our assessments.

WARSIM represents floating-point domains using an IEEE double. LC2IEDM floating-point domains are specified as NUMBER(m,n) where m represents the total number of digits and n represents the number of digits after the decimal point. We expressed the degree of alignment as $1 - r s / m$, where r is the percentage of the range covered by the LC2IEDM, and s is the number of significant digits that NUMBER(m,n) can't represent.

One issue is how divergent domains can be and still rate a high degree of alignment. For example, WARSIM records IDs as strings, whereas the LC2IEDM records them as 15-digit integers. In practice, a simulation doesn't use anywhere near 10^{15} identifiers. Therefore, it's possible to define a function that unambiguously maps WARSIM IDs to LC2IEDM IDs, and vice versa. We decided to assign 100% as the degree of alignment whenever we could unambiguously map one domain into another.

4.2.2 Assessing Non-Standard Mappings

One problem encountered in aligning classes from WARSIM with entities in the LC2IEDM is that a particular class used in WARSIM may not be distinguished as

such in the LC2IEDM, although a more general class (or superclass) may accommodate the data involved. Many examples of this type were found when assessing the TCDM terrain classes (such as "Amusement Park") used by WARSIM. Many such classes could be mapped into either the FEATURE or FACILITY entities of the LC2IEDM, and their types could be recorded in the OBJECT-TYPE-NAME attribute. However, there is no standard name or entity in the LC2IEDM that is specific to these problem classes. Hence, the LC2IEDM itself provides no standard means of representing such classes, and different systems could map the same type of feature or facility into different object names. Thus, in such cases, a lower level of alignment is assigned at the Entity level to reflect this absence of a standard means of representing the class.

5 WARSIM to LC2IEDM Results

We have not completed assessment of all WARSIM-managed elements, so the degrees of alignment below are not finalized. However, the analysis is complete enough to sustain the recommendations presented in this paper.

5.1 Unit

WARSIM and the LC2IEDM both have explicit entities for representing military units. WARSIM has the org.land.unit object class, which corresponds to the UNIT subclass of the ORGANIZATION entity in the LC2IEDM.

An example of mapping Unit area attributes from WARSIM to the LC2IEDM is illustrated in Figure 4. The task attribute of org.land.unit is shown to map directly to the action name attribute of the ACTION-TASK entity in the LC2IEDM. However, the six other entities shown are required to link the action task to the Unit entity and to specify the task as in execution and in progress. The frequency attribute of org.land.unit in WARSIM, in contrast, has no corresponding data element in the LC2IEDM.

Figure 5 shows the results of all 69 State-level assessments in the Unit area, 5 of which were identified as not applicable (N/A) due to irrelevance to C4I systems. This graph breaks down the assessment of alignment in the Unit area in terms of ranges of degree of alignment for the attributes. A majority of the attributes assessed fully align (at 100%), and the overall degree of alignment of the Unit area is 75%.

5.2 Equipment

WARSIM does not generally model individual instances of equipment, but rather models equipment groups. An equipment group is a type of organization. Each equipment group comprises a set of platforms and crew members, along with movement data for each platform (i.e., a list of movement segments planned or recorded for the platform).

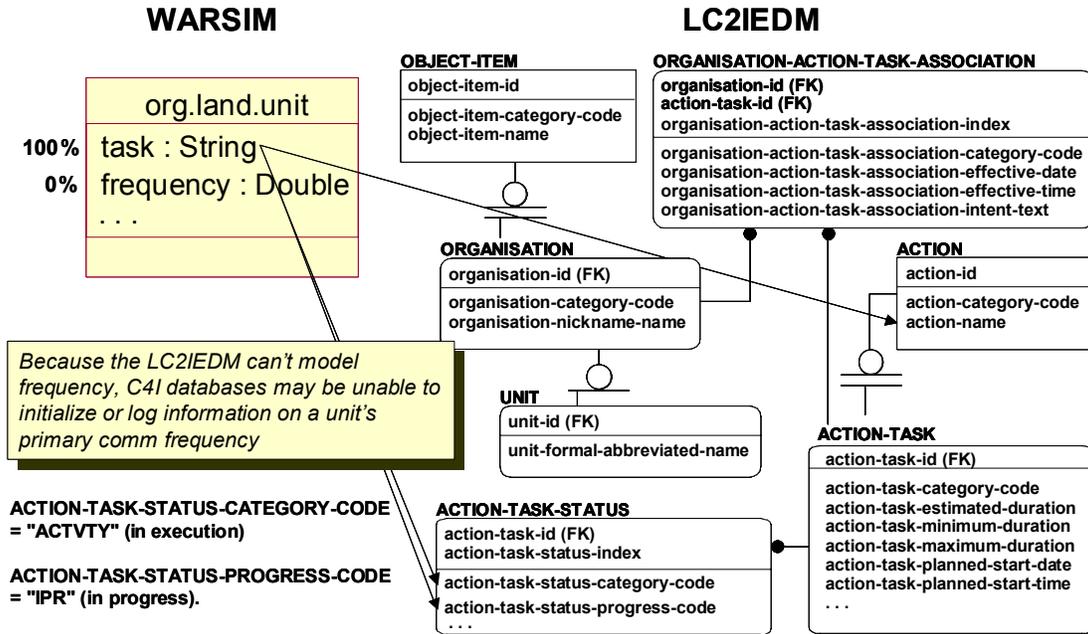


Figure 4. Example Unit area alignment mapping and assessments

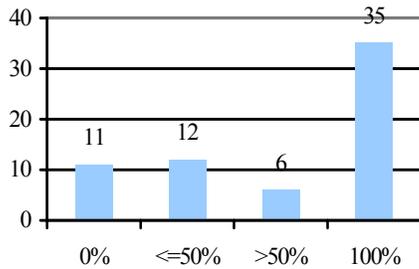


Figure 5. Unit area alignment assessment results

We assessed 18 JSIMS classes and complex types as part of assessing alignment in the equipment area. This required State-level assessments of 68 attributes, and 29 Value-level assessments of JSIMS domains. Figure 6 shows that the majority of attributes had a degree of alignment between 50% and 100%; however, there were 14 attributes that did not align at all. The overall degree of alignment for the equipment area was calculated to be 57%.

Examples of the mappings from WARSIM to the LC2IEDM are presented in Figure 7. The strategy for modeling an equipment group in the LC2IEDM is to model it as an ORGANISATION, and the platforms within it as MATERIEL. The association between an equipment group and its equipment is then modeled by the ORGANIZATION-MATERIEL-ASSOCIATION associative entity.

5.3 Environment

An alignment analysis was performed on all 167 TCDM features. Following an Entity-Level assessment, the 85 attributes described in the TCDM were evaluated in a State-Level assessment. Finally, the 13 TCDM data types were evaluated in a Value-Level assessment.

Most of the TCDM features were mapped to the LC2IEDM FACILITY-TYPE entity. The rationale for this was that there appeared to be a direct semantic map. That is, not only did the LC2IEDM include an Entity Category Code (ECC) for the specific feature under analysis, but examination of the attributes of the TCDM feature indicated that the semantics of the feature and the LC2IEDM entity were very close. Examples of these TCDM features include Airport, Infantry Trench, and Minefield. Additional mappings to the LC2IEDM FEATURE-TYPE entity for these same TCDM features is also possible. In some cases this may be the more appropriate mapping. For instance, Aqueduct was mapped to the LC2IEDM FACILITY-TYPE entity but could also be mapped to the LC2IEDM CONTROL-FEATURE-TYPE entity if the goal was to depict the feature in a display, a map, or an overlay.

A small number of TCDM features mapped naturally to subtypes under the LC2IEDM FEATURE-TYPE entity. If a TCDM geographic feature had no corresponding ECC in the LC2IEDM, it was mapped to the LC2IEDM GEOGRAPHIC-FEATURE-TYPE entity. Examples of TCDM features that mapped to GEOGRAPHIC-FEATURE-TYPE

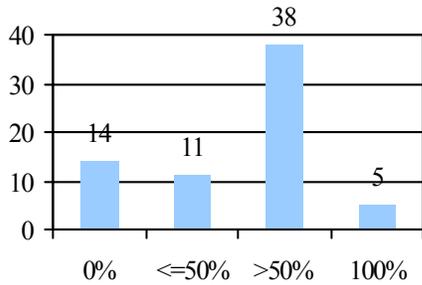


Figure 6. Equipment area alignment assessment results entity include Bamboo/Cane, Bluff/Cliff/Escarpment, and Fault.

Similarly, some TCDM features for which there was no corresponding ECC in LC2IEDM mapped to the CONTROL-FEATURE-TYPE entity. Examples include Aqueduct Centerline/Nexus, Armistice Line, and Demilitarized Zone.

In some cases, the mapping from TCDM features to LC2IEDM entities was not intuitive. TCDM feature ClearedWay/Cut/Firebreak maps to the FACILITY-TYPE entity in LC2IEDM rather than to the CONTROL-FEATURE-TYPE entity because there was an exact ECC. TCDM feature Breakwater/Groin was mapped to FACILITY-TYPE because an ECC exists for Jetty, which was semantically close. TCDM features Hops and Rice field were also both mapped to the FACILITY-TYPE entity in LC2IEDM because an ECC exists for Cropland, rather than to the GEOGRAPHIC-FEATURE-TYPE entity, as one might have expected.

An even smaller number of TCDM features mapped to the LC2IEDM EQUIPMENT-TYPE entity. These include TCDM features Airport Lighting, Crane, Disk/Dish Antenna, and Nuclear Reactor.

In accordance with the alignment study method, the degree of alignment of each of the features described in the TCDM is expressed as a percentage. The features and their degree of alignment were then allocated to the appropriate coverage, and an average degree of alignment calculated for the coverage. The results are shown in Table 2. This table shows that the overall degree of alignment between the TCDM and the LC2IEDM is 51%.

Table 2. Degree of Alignment by Coverage

TCDM Coverage	Degree of Alignment
Surface Areas	
Physiography	33%
Vegetation	28%
Urban	54%
Water	32%
Point Culture	71%
Linear and Point Hydrography	39%
Linear and Areal Terrain Obstacles	56%
Maritime Trafficability	43%
Linear and Point Transportation	52%
Administrative Boundaries	43%
Battlefield Elements	88%

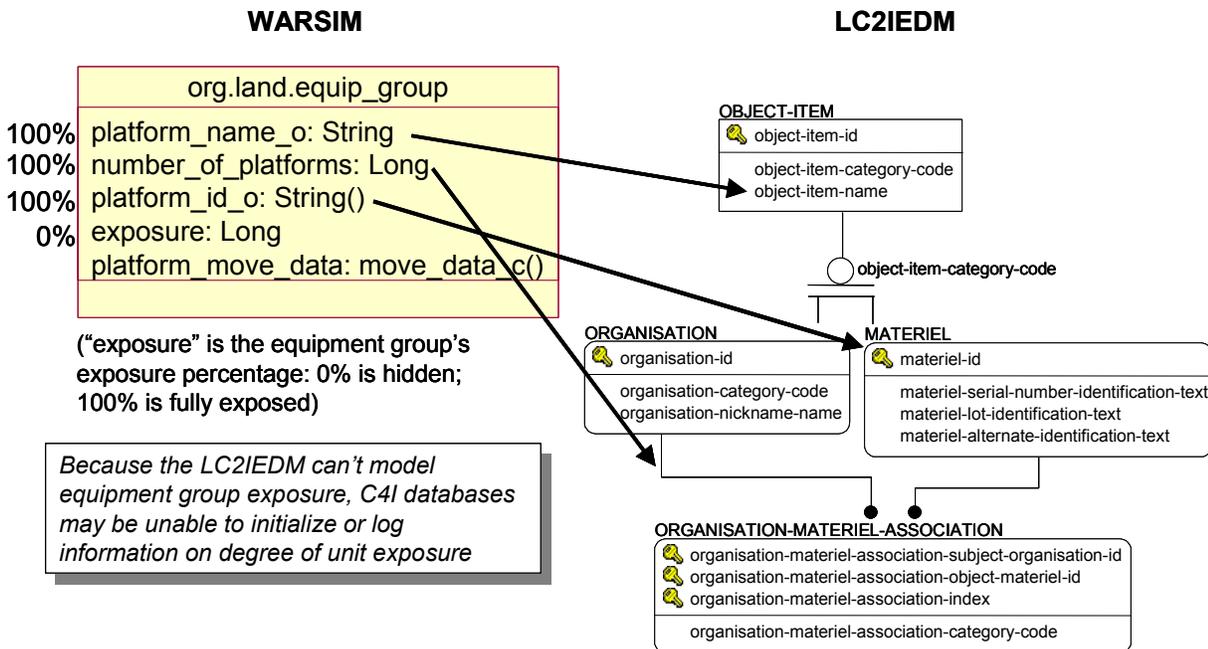


Figure 7. Example Equipment area alignment mapping and assessments

TCDM Coverage	Degree of Alignment
Linear Connectivity	79%

Significantly, the Battlefield Elements coverage provides the highest degree of alignment at 79%. One goal during model development was to represent concepts from the warfighter’s perspective. Surface Areal coversages with a poor degree of alignment with the LC2IEDM. Since the version of the TCDM used in this study focuses primarily on terrain, and does not yet include features describing a complete Synthetic Natural Environment (SNE), it is conceivable that the Surface Areal coverage will offer greater alignment with the LC2IEDM in the future.

Figure 8 shows the results of 79 State-level assessments in the Environment area. All were relevant, 58 were terminal, and a majority had zero level alignment.

5.4 C4I

The C4I and C2 object classes published to the JSIMS FOM by WARSIM have no corresponding LC2IEDM data elements. Those C4I/C2 object classes and attributes whose names end with “_p” (for “private”) are used only by WARSIM for initialization. The C4I object classes provide an interface between the simulation and C4I system to translate to/from standard C4I messages using DTD (Document Type Definition), which is a set of rules that defines the elements, and their attributes, in an XML (Extensible Markup Language) document. These objects initialize and hold the state needed by the C4I systems. The LC2IEDM does not contain data related to specific system implementations. Rather, the LC2IEDM represents battlefield objects commonly tracked by (primarily) land-based command and control systems. The following WARSIM C4I/C2 object classes were reviewed:

- `c2_artifacts.land`: land-specific C2 artifacts
- `c2_artifacts.land.state`: parent class for data tables required to hold state needed by the C4I systems. Contains 4 complex and 4 atomic attributes in the following 2 object classes (#complex/#atomic):
 - `c4i_handler` (2/2): contains the state of the C4I handler.

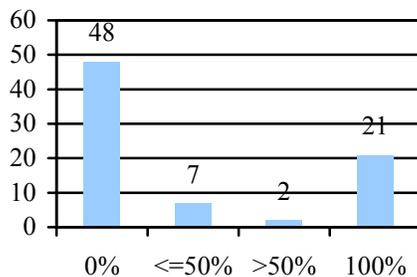


Figure 8. Environment area alignment assessment results

- `toc_handler` (2/2): contains the state of the TOC handler.
- `initialization.land.c4i`: superclass for data tables required to initialize the C4I systems. Contains 10 complex and 98 atomic C4I attributes in 15 object classes. Examples of these object classes (#complex/#atomic) are:
 - `jsims_interaction_manager_p` (0/8): C4Ihandler receives this FO, converts the data to XML format, and sends to CommunicationsManager to write the JSIMSInteractionManager XML data to disk via C4iiRemotelnSim.
 - `communications_manager_p` (1/3): TOCHandler receives this FO to create CommunicationsManager.

This study did, however, assess WARSIM battlefield objects and attributes related to C4I that were included within the organization/equipment object classes. Examples include `org.land.comms_status`, `org.land.terminal_status`, `org.land.radio_status`, `org.land.sensor_status`, `org.land.type = MSE` (mobile subscriber equipment), `org.land.type = SIGNAL_CORPS`, `abstract.land.radio_capability`, `abstract.land-terminal_capability`, `abstract.land.sensor_capability`, and `org.land.unit.terminal_address_o`.

6 LC2IEDM to WARSIM Results

The LC2IEDM to WARSIM Alignment assessment in the reverse direction, from the LC2IEDM to WARSIM, concentrated on two areas: Unit and Equipment.

6.1 Unit

Figure 9 shows the major LC2IEDM entities that participate in modeling a unit. Each unit is modeled as an instance of the UNIT entity, a subtype of ORGANISATION, which is a subtype of OBJECT-ITEM. An OBJECT-ITEM has associated type and status information. An ORGANISATION exists in relation to other organizations, via the ORGANISATION-ORGANISATION-ASSOCIATION entity.

WARSIM models a unit as an instance of the `org.land.unit` class. This class has implicit associations to the abstract class and its subclasses, which characterize properties of any unit of a given type.

The LC2IEDM’s structure for modeling units is much richer than WARSIM’s. The most significant difference is that WARSIM only models subordinate and supporting units, whereas the LC2IEDM enumerates 45 different types of associations (full control, tactical control, operational control, etc.) between units. Moreover, the LC2IEDM models some organizational capabilities that WARSIM does not. For instance, the ORGANISATION-ORGANISATION-TYPE-ESTABLISHMENT entity lets the LC2IEDM describe nominal organizational composition

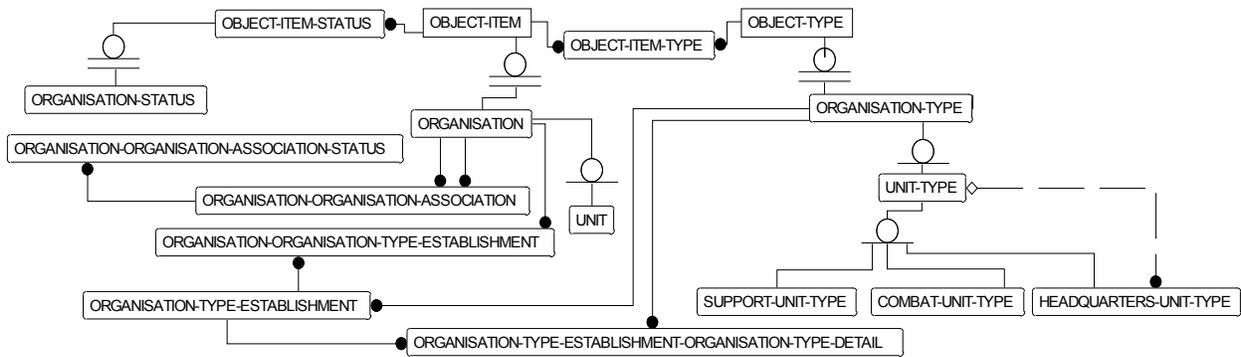


Figure 9. LC2IEDM Entities in the Unit area

and strength; WARSIM lacks this capability. A more specific example is the UNIT-TYPE-MOBILITY-CODE attribute, which characterizes a unit’s mobility; WARSIM has no equivalent.

Figure 10 shows the results of the reverse alignment assessment for the Unit area. Of 36 LC2IEDM attributes assessed, slightly under half align fully, but 30% do not align at all. The overall degree of alignment of the Unit area is 45%.

6.2 Equipment

The LC2IEDM can model each instance of equipment that an organization possesses as an instance of MATERIEL. Figure 11 shows the major LC2IEDM entities that participate in modeling equipment. Each instance of equipment is modeled as an instance of MATERIEL, which is a subtype of OBJECT-ITEM. An OBJECT-ITEM has associations to type, status, and capability. Subtype relationships provide further categories.

WARSIM models some instances of equipment (though it more often models equipment groups; see Section 5.2) as instances of the equipment and platform classes. WARSIM describes equipment types as instances of the abstract class and its subclasses.

Figure 11 clearly illustrates the rich set of equipment modeling relationships that the LC2IEDM provides. The LC2IEDM has specific entities for modeling status and

capability. WARSIM, by contrast, has no classes designated for describing status and capability; it only assigns class-specific attributes. Moreover, the LC2IEDM provides (via associative entities such as OBJECT-ITEM-TYPE) many-to-many relationships between major entities (such as OBJECT-ITEM and OBJECT-TYPE), whereas WARSIM’s class structure only provides one-to-many relationships.

LC2IEDM’s comparative wealth of modeling capability in the equipment area suggests it will not align well to the WARSIM, a hypothesis borne out by our assessment. We assessed 16 entities and 58 attributes. Figure 12 shows the results. Over 1/3 of the attributes did not align at all, and over 2/3 aligned less than 50%. The overall degree of alignment for the equipment area was 36%.

7 Study Recommendations

7.1 LC2IEDM Enhancements

Several recommendations can be made for enhancements to the LC2IEDM. In creating these recommendations, the study evaluated what changes would be beneficial for the general class of Simulations to which WARSIM belongs. Thus, the changes recommended were not specific to WARSIM, but would support requirements from the larger class of constructive simulations.

7.1.1 Scope

Suggested enhancements to the LC2IEDM are organized by the three assessment areas: Unit, Equipment, and Environment.

7.1.2 Recommended Changes for Simulation Unit Data

The enumerations for the types of units in LC2IEDM need to be expanded to reflect more closely the data requirements in simulations. In addition, structures for handling information exchange requirements, such as those that exist in other large standardized models (e.g., the C4ISR Core Architecture Data Model (CADM)) may be needed

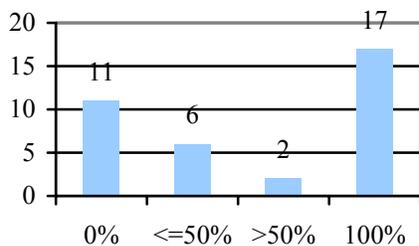


Figure 10. Unit area reverse alignment assessment results

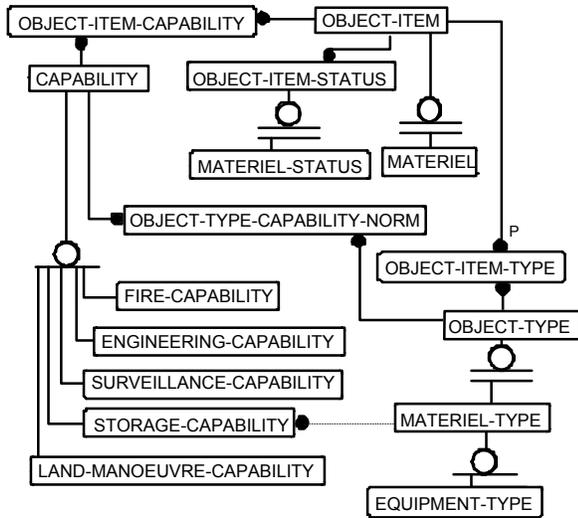


Figure 11. LC2IEDM entities in the equipment area

to handle aspects such as the frequency of the messaging among nodes, the timeliness of the data, its temporal validity, etc. The same is true for those simulation data requirements that express assessments of the unit with respect to its activities, e.g., mission effectiveness and morale, that currently cannot be specified other than as text, e.g., via the LC2IEDM structure CONTEXT. Finally, it may be necessary in LC2IEDM to provide enumerations that reflect assessments in a quantitative form rather than in general terms, e.g., percentage of concealment of a unit, as opposed to the general activity of hiding as part of an action specified for that military unit.

7.1.3 Recommended Changes for Simulation Equipment Data

As in Section 7.1.2, there is a need for enlarging the enumerations in LC2IEDM to handle the numerous equipment types specified in the simulation model, but, perhaps more importantly, for introducing the concept of PLATFORM as an explicit subtype of MATERIEL-TYPE to enable a closer alignment between the two models. The need in LC2IEDM for quantitative enumerations, e.g., as percentages, is also present here. The motion of units in LC2IEDM is primarily along 2-dimensional paths. The model does not support multiple geodetic reference models, expecting every entry to be referenced to the WGS84 standard. Allowing for different coordinate systems of reference and for 3-dimensional paths would permit the handling of spatial trajectories, orbits, etc., as well as direct upload and download of coordinates without intermediate transformations.

In fairness to the LC2IEDM it should be noted that the domain value level specification in WARSIM elements published to the JSIMS FOM were not sufficiently explicit

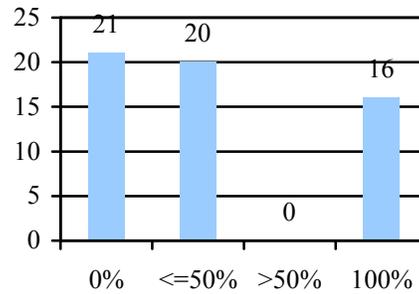


Figure 12. Equipment area reverse alignment assessment results

as to allow unambiguous interpretation of the meanings of those values.

7.1.4 LC2IEDM Enhancements to Support WARSIM Environment Data

What has been said with respect to the Unit and Equipment classes in WARSIM applies equally so to the Environment class, namely, that a substantial expansion of the enumerations in LC2IEDM is needed to better support the data requirements of the simulation. On the other hand, it is not clear from the data provided in the Terrain Class Data Model (TCDM) whether all the classes are primarily used as map overlays, and, therefore, ought to be treated simply as instances of the LC2IEDM entity FEATURE-TYPE, or whether in fact those classes that one normally view as instances of facilities or equipment are in fact used as such in the simulation. There is, therefore, in the current alignment assessment a certain amount of over-specification, because some classes in WARSIM correspond to enumerations in FACILITY-TYPE in LC2IEDM, while others appear to map cleanly to enumerations in FEATURE-TYPE. This in turn forces the use of extra entities such as FACILITY-FEATURE-ASSOCIATION to permit the use as a FEATURE a WARSIM class that has been mapped originally as a FACILITY-TYPE because of the existence of an enumeration that matches identically the simulation requirement.

Last but not least, there is a need to enlarge the set of attributes in LC2IEDM that characterize either a FEATURE or a FACILITY so that all of the 86 attributes that TCDM specifies for its environment classes can be captured in LC2IEDM, as opposed to only 41 currently.

7.2 Modeling And Simulation Recommendations

WARSIM was found to cover only 45% of the LC2IEDM Unit area data elements, and 36% of its Equipment area data elements. This indicates that WARSIM (as represented by its elements of the JSIMS FOM) has substantial limitations in being able to represent information that is important to effective C2 operations. Some of these limitations are a reflection of using an HLA FOM as the

model source, since a FOM cannot represent class associations (such as unit command structure) except for class inheritance hierarchies, even though the underlying simulation may support them. Thus, it would be helpful in assessing a simulation's modeling capabilities and its potential for effective data interoperability, to have additional sources of modeling information. Such information could be provided either by maintaining current design and implementation models in addition to a FOM, or by supplementing a FOM with just the neglected associational information.

Even neglecting the absence of association information, the WARSIM data elements fell far short of capturing all the types of data used in C2 interchanges. The mismatches between the models examined indicates that Army M&S systems may benefit from a reference object model which identifies all relevant C4I data elements within the context of a structure that would be applicable to M&S design. Development of such a model is a natural next step.

8 Future Work

As a result of the studies sponsored by ODISC4 [5] and the SIMCI OIPT documented in this paper and [6],[1],[15], the US Army has determined to develop an Army Standard C4I Object Model that would represent the LC2IEDM and JCDB data structures to the Simulation Community. The US Army Communications and Electronic Command Research and Development Center (CECOM RDEC) is forming a working group across the Army to manage and coordinate the development of this model. This is a three-year effort and is expected to be a significant advancement in Army C4I/M&S Interoperability.

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