Converging Simulation and C2: Improving Foundation Data Consistency and Affordability

Michael Hieb
C4I Center at George Mason University
Fairfax, VA
mhieb@c4i.gmu.edu

Daniel T. Maxwell
KaDsci, LLC
Fairfax, VA
dmaxwell@kadsci.com

ABSTRACT

Developing Modeling and Simulation (M&S) Terrain Data Bases for Army training events has been one of the most perplexing issues in Army M&S. Generating the necessary terrain data for the supporting Simulations, as well as Command and Control (C2) Systems, for training is extremely expensive and requires extensive lead-time. Historically, there were significant differences in the resolution and type of data that was required for military simulations and for operational decision support tools. For the last 10 years there has been an ongoing debate between the M&S and Operational Communities concerning which community has the “better” standards. However, a value analysis of the problem shows that most of the effort is put into obtaining and refining geospatial (and image) source data, and that this process can be the same for both communities. This paper describes findings of a US Army Simulation to Mission Command Interoperability Overarching Integrated Product Team (SIMCI OIPT) Geospatial Initiative focusing not on the differences but on the similarities between the two communities.

The implication is that the data requirements for all these systems are converging and becoming more demanding. Unfortunately, the various communities have, often for good reason, implemented different and inconsistent data related processes, standards, and policies for representing the same things in the different domains. These inconsistencies seriously limit the interoperability of systems, the reusability of geospatial data and ultimately the overall effectiveness of our C2 systems. Achieving the interoperability and meeting the increased demand systems users now demand requires that the M&S community increase its production efficiency and, critically, the consistency of the data that is the lifeblood of all these systems. Special emphasis in the paper is given to Co-Production of M&S and Operational geospatial data generation, which has been identified as a critical part of the current SIMCI effort.

ABOUT THE AUTHORS

Michael Hieb is a Research Associate Professor at George Mason University’s Center for Excellence in Command, Control, Communications, Computers and Intelligence (C4I Center) and a Technical Director for the Army’s SIMCI OIPT. Dr. Hieb’s research has concentrated on formalizing Command Intent for C2 Systems and Simulations. This has involved starting NATO and IEEE working groups and has spanned the fields of Computer Science, Networking, Semantics, and Computational Linguistics. Dr. Hieb has over 100 Publications and has presented his research on Command Intent to many International C2 and M&S Forums, as well as tutorials at I/ITSEC and SISO.

Daniel Maxwell is President of KaDSci, LLC, a small decision sciences research company that provides services to multiple government agencies and commercial clients. Dr. Maxwell completed a full career in the US Army where he served as the Technical Director of the Joint Warfighting Simulation System (JWARS) Office in the Office of the Secretary of Defense (OSD). Dr. Maxwell is a member of the Intelligence Community Strategic Studies Group and has also served previously on the Defense Science Board Task Force on Intelligence, as well as a member of the Military Operations Research Society Board of Directors. Dr. Maxwell has research interests and has published in the areas of decision analytic modeling, simulation, resource allocation, and modeling and analysis for organizational leaders.

Converging Simulation and C2: Improving Foundation Data Consistency and Affordability

Michael Hieb
C4I Center at George Mason University
Fairfax, VA
mhieb@c4i.gmu.edu

Daniel T. Maxwell
KaDsci, LLC
Fairfax, VA
dmaxwell@kadsci.com

INTRODUCTION

The training community has been creating and customizing environmental data for use in various Department of Defense and commercial simulations since the 1960s. During the fifty years that simulations have been in development and use, the resolution of the environmental data they require has increased on pace with increased computing power and visualization capability. The result has been the development of very high fidelity simulations to support training, concept development, experimentation, analysis, and system testing. Accompanying this increase in fidelity has been a continually rising cost to provide the environmental data these simulation systems require.

During the same period, Mission Command in the US Army (A note on terminology – The Army uses Mission Command to refer to the C2 domain. In this paper, C2 – Command and Control – is used as a more widely understood term) has been processing and using a subset of the same source data as a foundation for populating C2 and other decision support related information systems; including other analytic models. Similar to simulations, many of these systems are demanding more highly resolved data, at a continually increasing cost to the Army. (As well as other elements of the Government and industry.)

In addition, developers across all of the information system communities have been faced with an increasing demand to create datasets that are interoperable across different simulations, mission command and other decision support systems. Unfortunately, this level of interoperability is not currently achievable using the existing heterogeneous collection of potential source data, software tools, and business processes.

In this paper, we present recommendations for how to improve geospatial data consistency as it pertains to supporting Modeling and Simulation (M&S) functionality in the C2 domain and present recommendations for how the situation might be improved. This involves the production of Terrain Data in the M&S Community, the application of new Geospatial Technologies, and improved sharing of Geospatial foundation data.

There are also issues that are not usually considered technical that impact the key area of sharing data. These issues involve the trustworthiness of data produced without a "pedigree" or by a trusted agent. Many of the technical issues, such as incompatible data formats or tools, need to be examined in the context of these other issues

The US Army's Simulation to Mission Command Interoperability Overarching Integrated Product Team (SIMCI OIPT), consists of over 30 Army Organizations that work to improve the interoperability of Simulations and C2 Systems. In August 2010, the US Army SIMCI OIPT established a Geospatial Initiative (which will be called the "SIMCI Geospatial Initiative" in the rest of this paper) to address the long-term problem of developing Terrain Data Bases for M&S applications that would be compatible with C2 systems. This paper gives the findings of the SIMCI Geospatial Initiative to date and also presents initial recommendations.

The charter of the SIMCI OIPT (Hieb, et al, 2002) directs the OIPT to work not in the M&S domain, nor the C2 domain, but rather in areas that involve interoperability between the two. While the SIMCI OIPT had not worked in the Geospatial area in its first years, it started to sponsor projects in this area in 2007-2010. These projects were only able to make limited progress due to larger interoperability issues (both technical and non-technical).

For many years, technical interoperability of terrain data between M&S applications and C2 systems was not possible due to incompatible data formats and representation standards. Progress in this area was very slow due to the significant differences in the density and types of data required by different C2 and simulation systems. In general, M&S applications require much more data, as well as a more highly resolved set of features and attributes, compared to that used by C2 systems. Moreover, there were only very minimal requirements for simulations to interact with Mission Command Systems.

In general, the SIMCI OIPT has found that the best interoperability solutions in the SIMCI area are based on formats and standards used by the Operational Army. For example, in the area of Force Structure data used to represent units, it is preferable to base solutions on the Operational Army formats used for ascertaining Unit Readiness (e.g., USR Reports) rather than particular M&S formats. While an M&S standard may appear very useful in the M&S Community, it often will not be able to be populated (by translation from the Operational formats) without significant loss of information and an accompanying loss of utility to the broader community that consume the data.

Indeed, in the Geospatial Data Community this has happened. M&S developers used specific formats and developed excellent technical standards such as the Synthetic Environment Data Representation and Interchange and Specification (SEDRIS) (Cox & Schaefer, 2000) tailored to the needs of simulations.

While the SEDRIS Standards are excellent for promoting interoperability in the M&S Community among simulation systems, the Operational Army has not embraced them. Thus, when an Operational Army Unit produces a terrain product, it cannot be easily transferred into a SEDRIS format. This causes limitations in how the M&S Community produces and distributes terrain data. Because the two sets of standards have different user communities and are not compatible, two support infrastructures have developed, each with their own specific tools. Now, 3D viewers and planning tools that rely on 3D data are becoming common in the Operational Army. The resolution of this data is very similar to that of simulations. This makes the inconsistency in standards and formats now a critical constraint on interoperability and data generation efficiency.

The SIMCI Geospatial Initiative has the goal of enhancing technical interoperability by achieving maximum consistency of Geospatial data between the two domains of C2 and M&S. This would mean that when a Simulation is running and simulating operations in a particular place, it would be geospatially consistent with any C2 systems that the simulation is interoperating with. This level of consistency is required if we are to eventually achieve true Live, Virtual, Constructive (LVC) interoperability.

Over the past 18 months the SIMCI Geospatial Initiative has had extensive meetings and conducted several workshops to identify the roadblocks to solving the problem of producing consistent and aligned geospatial data. Analysis over the past year has revealed that 80% of the effort in building unique M&S Terrain Data is expended to develop consistent and accurate “Foundation” data. A typical production process for developing M&S Terrain Data begins by performing initial processing of the source data to “clean it up” and then to take this source data and generate a “run-time” database. It can be seen that there is a process of “cleaning up” (or more euphemistically “enhancing”) source data, in many cases this data is obtained from the National Geospatial-Intelligence Agency (NGA). However, this is fundamentally the same process as is found in the C2 world. Both M&S and C2 Geospatial data production processes need to “clean up” the source data prior to tailoring the data for their specialized purposes (“Value Adding") and ultimately generating an application ready “terrain product” such as a run-time database.

Thus, rather than continuing to concentrate on the difference in data formats, the community can work on improving terrain consistency for the 80% common effort at the front of the production process. This is the fundamental premise driving the recommended “To-Be” process outlined later in the paper.

Other issues such as Trust in the accuracy of data have also worked against the M&S Community in helping the standards converge. For example, a simulation database developer might modify the width of a road slightly to allow synthetic forces to traverse that road and complete an automated transportation network or a high resolution 3D building might have artificially created interior detail to enhance the “realism” of the training experience. In both of these cases simulation artifacts introduce inaccuracy and false precision into the data that could be detrimental in an operational C2 system.

The remainder of this paper is organized as follows: “Background” gives a historical perspective of why there is divergence between M&S and Operational Terrain. “The Impact Of The Lack Of Correlation” shows why geospatial interoperability is important. “Key Issues In Achieving Geospatial Convergence” presents an analysis of these key issues. “Achieving Consistency From Best Practices” presents an overview of the Best Practices that SIMCI is developing for M&S Terrain Producers. “Conclusions” concludes with recommendations to improve Geospatial Interoperability.

BACKGROUND

In order to develop appropriate recommendations, it is necessary to see why the current situation has developed as it has. The existence of two different communities of producers using different tools and formats has occurred for many reasons. In some cases the differences are the result of clearly different needs in each community; in other cases the differences are attributable to a natural lack of communication between the communities because there were only very limited needs for interoperability. There are many aspects of the operational and technical situation that have changed in the past ten years that can be used to converge to common solutions.

Evolution of Standards

As noted above, there are several different sets of standards in use in the M&S Community, and a substantially different set of standards in use in the Operational Army.

The M&S Community requirements have been driven by the need for computationally efficient Terrain Database run-time formats. This is due to what were exacting requirements caused by constrained processor speed, run-time memory and hard disk storage of simulations. In order to achieve realistic behaviors, the terrain databases used needed to be highly optimized for performance in the three areas above.

Ten years later, with more powerful computing infrastructure, and advanced and efficient simulations, there is less of a need for technically optimized terrain formats. What still remains is a need for consistency so that virtual entities (e.g., ground vehicles) can traverse representations of terrain. Discontinuities in road segments that would be acceptable in a highly aggregated terrain product for designed human viewing affect a virtual entity's mobility. This is because a gap, no matter the size, affects the planning and movement algorithms in a simulation.

The use of Terrain Databases for 3D Visual use in Simulators, such as the Close Combat Tactical Trainer (CCTT), was another area where the M&S Community required a much higher density of data, and more features, than Operationally oriented Mission Command systems. The DARPA Synthetic Theater of War program also developed new M&S technologies that required higher resolution terrain data. This requirement led to the SEDRIS family of standards improving the ability to transmit Terrain Data between different Simulators.

The Operational Army took a different approach and developed the Digital Topographic Support System (DTSS), relying heavily on Geographic Information System (GIS) technology. This was due to the need to produce map products designed to inform human decision-making. There was a need for more coverage and an emphasis on mobility analysis. In order to take advantage of this GIS technology, the Army purchased an Enterprise License of a commercial GIS system, ArcGIS by the Esri Company. This is called the Commercial Joint Mapping Took Kit (CJMTK) and is described in the next section. (It should be noted that M&S Terrain Producers often use GIS tools when they produce M&S terrain data – see the Section "Co-Production Processes and Standards" later in the paper).

Geospatial Tools for Mission Command

Mission Command systems are largely focused on providing visual cues that support operational decision-making, usually in near real time. This requires that they have the most current data possible and that it be visually accessible to humans. GIS technology has been developing over the past four decades to accomplish exactly that for many purposes

The Commercial Joint Mapping Toolkit (CJMTK) is a NGA program that provides the required geospatial information management, analysis, and visualization functionality for command, control, and intelligence (C2I) mission applications.

The CJMTK provides common geospatial tools to use across the DoD. Commonality of platforms, software tools, and processes is a critical factor in assuring interoperability across C2 Services. Also, adoption of commercial industry standards reduces overall integration costs for the various DoD mission applications. The CJMTK is based on a single scalable open architecture, with open development environments, incorporating industry standards, where significant research and development costs are borne mainly by vendors, offering regular software upgrades, extended functionality, and standard, regular training.

Recently the CJMTK has been used on a prototype basis to directly provide terrain services to Army Simulations (Stanzione & Johnson, 2007).

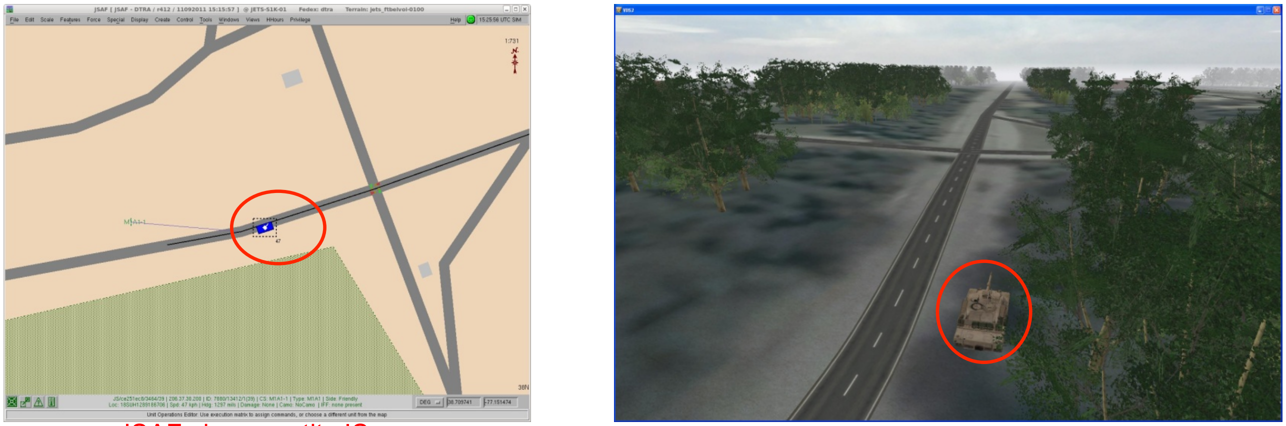

Figure 1 – Example of X-Y Miscorrelation

While the CJMTK is being used across the Army Enterprise for Geospatial Processing, there is increasing use of other capabilities such as Google Earth (Google, 2012) and NASA World Wind (NASA, 2012) for visualization in Army C2 Applications and Systems such as Command Post of the Future. This adds a new complexity to achieving geospatial interoperability, and is still a topic of investigation for the SIMCI Geospatial Initiative.

THE IMPACT OF THE LACK OF CORRELATION

Terrain representation across a simulation federation must be consistent; otherwise there is a good chance that visual and logical inconsistencies can be introduced that could undermine training or analysis. Terrain databases in different run-time formats can be used as long as they are consistent with each other. These are known as correlated terrain databases. Deviation from this correlated terrain can result in both technical and operational problems.

Terrain database producers must be aware that producing correlated terrain databases with multiple tools is very difficult. When possible, terrain database producers should use the same tool to create different run-time database products. For example, a terrain database producer may be tasked with creating correlated OpenFlight (a commercial widely used 3D Visualization format) and Objective Terrain Format (OTF) (a format often used for OneSAF Terrain Data compliant with SEDRIS) databases for application in the same training event. The terrain database producer could create the run-time databases using the same tool (for example, either TerraVista or TerraTools), but should not create the OpenFlight in one tool (e.g., TerraVista) and the OTF in another tool (e.g., TerraTools). This is because the triangulation (TIN'ing) algorithms in each tool are different and could produce different results in the run-time products.

There are two primary types of miscorrelation: X-Y miscorrelation and Z miscorrelation. When two databases are X-Y miscorrelated, the location of various features may differ on the surface of the terrain. One simulation may view an entity driving along the road, while the other simulation may view the entity driving beside the road as shown in Figure 1. This could cause major problems with combat adjudication, line of sight analysis, and other entity interactions. Z miscorrelation is when the two databases disagree about the absolute elevation of a given feature or terrain polygon. For example, one simulation may view the terrain surface at 1200m above sea level, while the other simulation may view it at 1210m above sea level. This can cause entities and features to float above the terrain surface or be submerged under it as shown in Figure 2.

KEY ISSUES IN ACHIEVING GEOSPATIAL CONVERGENCE

It is clear that with both the scarcity of Terrain Data & Products and the need for consistency, there is increasing motivation to use the same source data and process it for its intended purpose using compatible techniques. This vision is extremely complicated because of the different production processes and organizations involved. In this Section we examine barriers to reuse in three areas: 1) Data Sharing – a high priority for all concerned; 2) Co-Production – the ability of M&S producers to generate terrain data to Operational Army Standards.; and 3) Tools and Standards – different formats have been seen as the

Figure 2 – Example of Z Miscorrelation

major problem in dividing the Operational Army and M&S Communities.

Data Sharing

The barriers to sharing data in DoD are well documented. Much of the Net-Centric Data Strategy attempts to address this. While repositories have been previously set up in the M&S Community (such as the Master Environmental Library – MEL), these have been developed as research projects; usually without long-term sustainment funding. This implies the need for business models and incentive structures that would encourage geo spatial data producers to identify the geographic areas of the world that they are working on, the specific products they are producing, and then make that data available for others to use.

The US Army envisions the concept of a "Standard, Sharable Geospatial Foundation". This foundation would contain data that is consistent across different types of systems and adheres to a set of standards. Figure 3 shows the classes that comprise foundation data. The most common subcategory is elevation (e.g., Digital Terrain Elevation Data (DTED) Level 2). Imagery is also common, and must be geo-referenced to the terrain postings. The amount and types of Feature data processed depends upon what is available from the source data. The subcategory of Models is more used by the M&S Domain, but we expect that the C2 Domain will be using more 3D models for Mission Planning and Rehearsal in the future, as the Special Forces do presently. Standards are needed for how to integrate 3D models into GIS (Operational) data.

Finally, after the initial processing, foundation data is stored in either a specific database for regional terrain products (the Theater Specific Geo Database used by the US Army's Geospatial Center is shown in Figure 3) or a master database used to store foundation data.

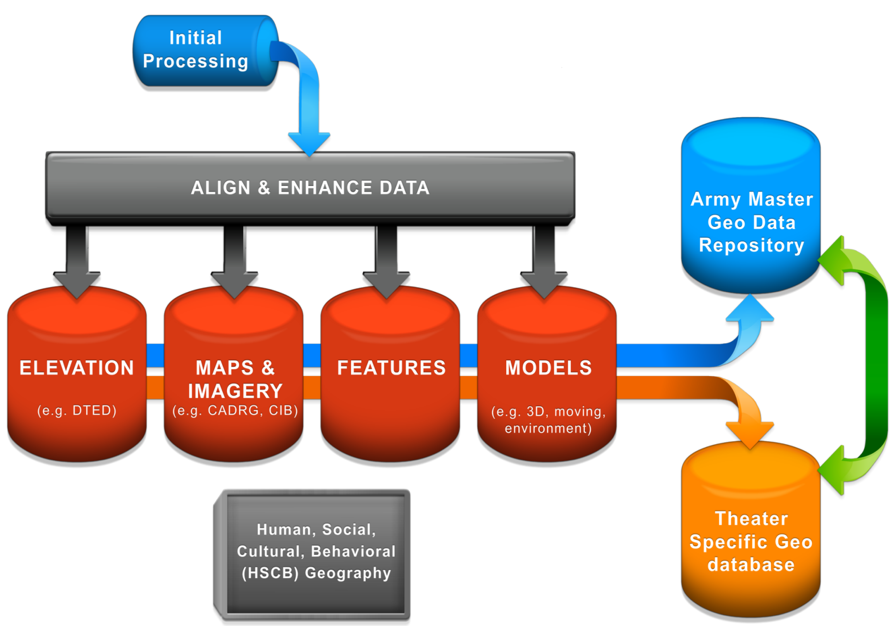

Figure 3 – Enhancing Geospatial Source Data

Co-Production Processes and Standards

Fundamental to reaching a consensus was arriving at the understanding that 80% of the effort in producing a Run-time Terrain Database or other geospatial product resides in the initial processes to reach the "Enhanced" Geospatial Data. After that data is developed, it can be readily shared and reused. Value Added processing is then performed to add or process any application unique data (such as 3D models or Geotypical Features). Once the "Process Source Database" is finalized, various tools can be used to put the data into a run-time format particular to a given simulation such as OTF for OneSAF (Robbins & Deakins, 2009).

Inputs to the "Initial Processing" step are source data (often obtained from NGA). Many different sources are now available depending upon the use of the final Terrain Product to be produced. However these sources need to be integrated, and also checked for consistency and accuracy.

Once the "Enhanced Geospatial Data" is produced, it is envisioned that it will be put back into a "Master" Army Repository. This is not systematically occurring at this point, although there are various repositories throughout the different Army Commands. A key hurdle is to ensure that the data provided for C2 systems meets Operational User requirements. This will require some certification of either the Data, the Producer, or both. In the case of the M&S domain, there is a unique issue – that of "fake" data. Often, either Geotypical or "Made-up" terrain features or objects are added to Geospecific Terrain to enhance the training experience. Obviously, this "fake" data should not be included in any terrain intended for Operational use. Ensuring that there is no "fake" data is a primary concern of the Operational Army Terrain Developers.

The SIMCI OIPT has sponsored a pilot product to develop a certification process for M&S Army Organizations. This is being performed by both the Army Geospatial Center and the Program Executive Office for Simulation, Instrumentation and Training in the US Army (Synthetic Environment Core - SE Core).

One way to manage the distinction between Geotypical and Geospecific terrain is through the use of structural Metadata. Currently there are several general Metadata standards available but none that are specific to this use.

Figure 4 shows a To-Be Architecture for Geospatial Data Processing for both C2 and M&S Systems. The C2 Systems in theater actually will have their data provisioned by US Army Terrain Warrant Officers working in Geospatial Production Cells. They will take the "Enhanced Geospatial Data" from the Master Army Terrain Repository to produce their terrain products. The M&S Systems (Simulations, Simulators, or Analytic Models), will use exactly the same "Enhanced Geospatial Data" to generate their run-time Terrain Datafiles. Using the same "foundation data" does not guarantee consistency unless the same tools are used to process the data for the same use. However, common foundation data substantially improves on the current situation where there can be significant inconsistencies between C2 and M&S data.

Figure 4 shows a tradeoff between where the data is common, coming from a common repository and from collection sources, and where it diverges, after being processed for specific uses. While it would be ideal for consistency if each system used the same data, Figure 4 also shows a process that would result in tangible improvements in interoperability, as well as enhance the quality and increase the production of M&S Terrain run-time Data.

Technical Standards and Tools

Much has been said already about the very different technical standards. However, the tools used also have an impact on interoperability. The formats that the tools support will have a great impact on the actual production of Terrain Databases for projects. One of the weaknesses of the SEDRIS standards is that many of the industry-developed GIS tools do not support them. Although SEDRIS helped the simulation interoperability problem by providing a consistent, integrated, and correlated view of the environment - for each interoperable simulation application to use, SEDRIS did not solve the broader interoperability and correlation problem of consistent terrain databases between M&S and C2 systems. However, using CJMTK does not address this issue as the CJMTK tools can use a variety of standards that are currently not aligned with SEDRIS. We discuss recommended best practices below that can achieve substantially improved alignment.

There are significant differences between the basic types of attribute catalogs used by M&S Terrain Producers such as the Feature and Attribute Coding Catalogue - FACC (Digital Geographic Information Working Group, 2000) and those used by NGA for Operational Data such as the National System for Geospatial-Intelligence (NSG) Feature Data Dictionary – NFDD (NGA, 2009).

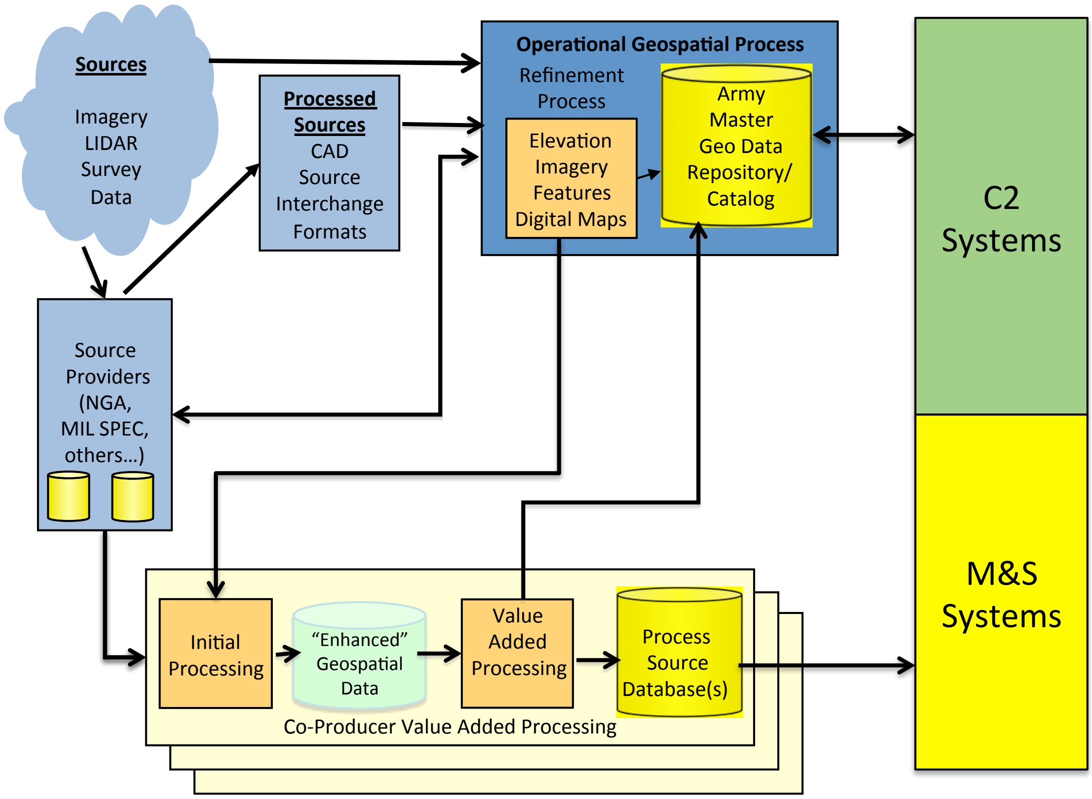

Figure 4 – "To-Be" State for Terrain Generation in the US Army

ACHIEVING CONSISTENCY FROM BEST PRACTICES

The SIMCI Geospatial Initiative realizes that if Co-Production and Sharing of Geospatial Foundation Data is to be achieved, there must be more commonality in the production processes of Producers of M&S Terrain Data. To achieve that, the SIMCI Geospatial Initiative has developed a "Best Practices Guide" (Maxwell et. al., 2012) that is currently being finalized for the Army M&S Community. This Guide has been presented to many of the SIMCI Geospatial Initiative Technical Exchange Meetings and has been extensively reviewed by Subject Matter Experts. We give the main points of the best practices guide below.

Organizational Practices (including both Government and Contractor best-practices)

1- Use an industry accepted and repeatable software development method. (Linear, Spiral, Agile, Bull-in-the-ring, etc)
Document end-to-end run-time format production processes used by your organization.

2- Invest in skill development.
GIS and run-time data base developers are normally hired to perform specific job duties and have specialized skills. They should be encouraged to continue development of their professional skills, both relating to current duties and those required for advancing the state of the art and practice in terrain data development. When possible, utilize commercial and government training opportunities to improve skill sets and increase capabilities.

3- Encourage programmatic investment for employees. (Leverage specifics within Statements of Work – SOWs)
Create opportunities to involve employees in the programmatic decision making and planning processes to ensure self-accountability and investment to achieve maximum desire for programmatic success.

4- Work closely with industry to ensure Commercial off-the-shelf Software (COTS) products enhance production methodologies. (Leverage specifics within SOW)
Ensure the Government harvests all technical data rights when acceptable, per Request for Proposal

(RFP) and SOW verbiage. Leverage lessons learned with previous Army contracts to guide work required for new M&S supporting terrain ventures.

Metadata Practices:

5- Maintain a versioned GIS data set. (corresponding to the run-time format)
Maintain a reference to or physical copy of versioned source GIS data tied directly to a product name. (i.e., Nebraska_GIS_version1.zip used to compile Nebraska_OTF_version1.zip). In addition, maintain a reference to any source data to indicate from what source a given piece of data is from. For example, if you "clip" out a section of Vector Map (VMAP) (DoD, 1996) data, retain a reference to that original source.

6- Document and use a naming convention.
Create a standardized naming convention for your organization and apply this to all products. It should allow for easy identification of format, version number, release date and database name. It should also be meaningful to data developers and database users that may wish to reuse the work.

7- Provide and maintain product Metadata.
Use documented metadata standards (such as the Defense Discovery Metadata Specification – DDMS (DoD, 2012)) to provide insight and transparency to products. Employ the use of discovery metadata

8- List the tools employed in your generation process.
Maintain a list of software tools used for run-time format generation Identify as Commercial off-the-shelf Software (COTS) or Government off-the-shelf Software (GOTS), and what role each tool plays in your production pipeline. Be knowledgeable about alternatives to your tools, while understanding the justification for the use of these tools by your organization.

Geospatial Practices:

9- Maintain and document a consistent feature extraction process.
Use a documented, repeatable process when creating new GIS data.

10- Perform Verification and Validation of your geospatial data (both created and acquired).
Use a data validation tool such as (but not limited to) Esri's Product Line Tool Set (PLTS) or the Institute for Defense Analysis' Geospatial Analysis Integrity Tool (GAIT) after creating or integrating new GIS data.

- The proper and efficient use of GIS creation methods can prevent common M&S data problems. (i.e., topologies, attribution scripting)
- This is especially important when working with datasets which are created from non-authoritative sources. These sources do not always guarantee quality GIS data. However, data produced by an authoritative data source may still have problems that can be identified using these tools.

11- Use and document a consistent data model and data dictionary.
- Use a data-model / data dictionary of some definition in a repeatable method while creating GIS data. (e.g., FACC, NFDD)
- Interoperate between data models and interoperate with the Army Geospatial Enterprise (AGE).
- Attribute all vector features as appropriate for your requirements and supplement with proper metadata.
- Provide data-model feedback to the owner / maintainer.

12- Use a single approved coordinate conversion and datum transformation method.
Document and use a consistent process, tied to an appropriate tool or method when performing Coordinate Transformation for example, NGA's GEOTRANS software or the SEDRIS Spatial Reference Model (SRM).

Run-time Practices:

13- Manage Triangular Irregular Network (TIN) and source elevations resolutions within the scope of program requirements; regardless of intended use of database. (delta tolerance)
- Understand and manage an appropriate range of difference for the TIN as it pertains to the source elevation used within the project.
- Understand and document all integrated features into the terrain surface and their effects on the polygonal surface of the product.
- In cases where TIN resolution is outside of a reasonable delta tolerance, document the difference as well as the run-time formats' intended use (applicable: metadata). For example, if a TIN has a delta difference of 99 meters from source DTED, but is being used in the context of the particular experiment or M&S application, document the reasoning.

14- Retain your run-time products for reuse when appropriate.
Maintain a copy of all DOD funded run-time products to allow for DOD-wide reuse, upon approved request. When possible, upload this data to appropriate repositories to maximize sharing with other DoD entities.

15- Retain all source data, intermediate files, and delivery packages for reuse when appropriate.
Maintain a copy of all DOD funded production materials to allow for DOD wide reuse, upon approved request, within an agency specific agreement system (Memorandum of Agreement – MOA, etc). If Intellectual Property (IP) has been purchased with limited repurpose rights, retain a copy of documentation for that situation.

16- Test your run-time products before release.
Perform and document internal run-time format test prior to releasing products for Army (DOD) use in a method appropriate to the scope of the program. Use automated tools as well as manual testing to ensure quality products.

General (Miscellaneous):

17- Clearly define requirements within run-time format Statements of Work.
Work closely with customer representatives to ensure that the appropriate requirements are stated in the SOW. Do this by clearly defining and documenting required program capabilities. When capable, cite industry studies and leverage the IPT process.

18- Make Application Programing Interfaces (APIs) available when they exist.
Provide API source code to users for any software written in support of the project.

19- Controlled DOD reuse.
- Support and control all DOD reuse, and assume agency specific responsibilities for export compliance etc.
- Use a redistribution ticketing system, where orders can be placed, tracked, and filled.

20- Maintain a knowledge base, contribute to current knowledge bases.
Maintain a record of lessons learned to increase software development efficiency over time (i.e., Internal Wiki, etc.); or, contribute to situation specific knowledge management systems (i.e., Milgaming/Bohemia Interactive forums for Virtual Battlespace 2 – VBS2).

CONCLUSIONS

A surprising finding of the SIMCI Geospatial Initiative is that Co-Production of terrain data by M&S data producers is a potentially high-value solution to the issues preventing geospatial interoperability. Due to the need to certify the processes that M&S Terrain Data Producers use, there will be increased standardization of both processes and formats within the M&S Domain. In addition, other Domains can use the same process to certify their Terrain Data Producers.

Focusing on the common aspects of geospatial data generation for the M&S and C2 Domains, will make a significant contribution to improving the efficiency of production processes as well as the ability to share and reuse data. Moreover progress in the areas where the communities have common interests will likely make addressing the more vexing aspects of the geospatial data challenge easier for all stakeholders.

Dialog between the SIMCI member organizations has been invaluable to achieve consensus on technical solutions and to build trust concerning the quality and potential reusability of M&S Terrain Data for Operational Use. We believe these discussions should continue.

All of this will contribute to the overall goal of ensuring consistency and alignment of Terrain Data between the US Army's C2 systems (that Soldiers use for operations) and of the US Army's Simulations, Simulators & Models (that Soldiers use for training, testing and experimentation).

ACKNOWLEDGEMENTS

The authors would like to thank the Subject Matter Experts and Advisory Group that are guiding the SIMCI Geospatial Initiative. These individuals have been invaluable in pointing out the many technical (and other issues) that need to be addressed as well as providing constant feedback and suggestions. We also thank Glen Quesenberry and Mark Seagrave for their direct support of the SIMCI Geospatial Initiative, as well as Mr. Erik Morton for the key role he played in the development of the Best Practices Guide that motivates much of this paper. We also thank the anonymous reviewers for their useful comments.

REFERENCES

Cross, A. Vierling, K. & Woodman, M. (2001). Synthetic Environment Standards for Marine Corps Training, Paper 11F-SIW-021, *Proceedings of the IEEE Simulation Interoperability Workshop*, Orlando, Florida, September 2011.

Robbins B. E., & Deakins R. (2009). Common Terrain Across the L-V-C Community. How the Objective Terrain Format (OTF) is supporting Live, Virtual, Constructive Simulations, Paper 09F-SIW-048, *Proceedings of the IEEE Simulation Interoperability Workshop*, Orlando, Florida, September 2009.

Cox, R. Dumanoir P., Hembree L., Mamaghani F., Trott, K. & Worley M. (2010). The Importance of Establishing Common Methods and Terminologies in Data Mappings, Paper 10S-SIW-051, *Proceedings of the IEEE Simulation Interoperability Workshop*, Orlando FL, March 2010.

Cox R., & Schaefer J.R. (2000). "The Synthetic Environment Data Representation and Interchange and Specification (SEDRIS)", *16th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, Long Beach CA., Jan 2000.

DoD, (2012). *DoD Discovery Metadata Specification (DDMS),* Version 4.1, June 12, 2012 – Office of the Assistant Secretary of Defense, Networks and Information Integration, Information Management, <http://metadata.ces.mil/mdr/irs/DDMS/>.

DoD, (1996). "*Interface Standard for Vector Product Format (VMAP)*, MIL-STD-2407, <earth-info.nga.mil/publications/specs/printed/2407/2407_VPF.pdf>.

Digital Geographic Information Working Group, (2000). *Digital Geographic Information Exchange Standard (DIGEST), Part 4: Feature and Attribute Coding Catalogue (FACC),* Ed. 2.1, 2000, <http://www.digest.org/Navigate2.htm>.

Google, (2012). *Google Earth*, <www.google.com>.

Hieb M.R. & Maxwell D. (2012). An Analysis of the Technical Interoperability of Terrain Data Between M&S and C2 Systems: Results from the US Army SIMCI OIPT Geospatial Initiative, Paper 12F-SIW-059, *Proceedings of the IEEE Spring Simulation Interoperability Workshop*, Orlando, Florida, September 2012.

Hieb M.R., Nielsen M., Pedersen K., Powers M., Pullen J. & Swann D. (2007). "A Standards-Based Framework for Integrating Command and Control Systems, Geospatial Information Systems and Simulations: Generating Actionable Geospatial Information", Paper 07E-SIW-043, *Proceedings of the IEEE Euro-Simulation Interoperability Workshop*, Genoa, Italy, June 2007.

Hieb M.R., Sudnikovich W.P., Sprinkle R., Whitson S.R., and Kelso T. (2002). "The SIMCI OIPT: A Systematic Approach to Solving C4I/M&S Interoperability", Paper 02F-SIW-067, *Proceedings of the IEEE Fall Simulation Interoperability Workshop*, Orlando, Florida, September 2002.

International Organization for Standardization (ISO). (2005). "Information Technology – Environmental Data Coding Specification (EDCS)", ISO/IEC 18025, 2005, <http://standards.sedris.org /#18025>.

Johnson K. & Stanzione, T. (2007). Tools for the Creation of Semantic Information for Modeling and Simulation. Paper ICCRTS-006, *Proceedings of the 12th International Command and Control and Technology Symposium*, Newport RI, June 2007.

Leite M.J. (2010). Development of Synthetic Natural Environments for Models and Simulations, Paper 10S-SIW-010, *Proceedings of the IEEE Simulation Interoperability Workshop*, Orlando FL, March 2010.

Maxwell, D., Cox, R., Quesenbery, G. & Morton, E. (2012). *Synthetic Terrain Generation: Best Practices – Guidelines for use in Developing Synthetic Terrain*, Version 0.99, SIMCI Geospatial Initiative Technical Paper, Dated June 2012, ≤http://c4i.gmu.edu/researchPgms/modelAndSimul.php>.

NASA (2012). *NASA World Wind Website*, <http://worldwindcentral.com/wiki/NASA_World_Wind_Download>.

NGA (2009). *National System for Geospatial- Intelligence (NSG) Feature Data Dictionary (NFDD),* Version 2.0, 27 February 2009, <http://www.gwg.nga.mil/ documents/asfe/NFDD_v2.0.pdf>.

Stanzione, T., Johnson K. (2007). GIS Enabled Modeling and Simulation (GEMS), *Esri User Conference*, San Diego CA, July 2007.

Wiesner, B. Stanzione T., and Brockway, D. (2011). Open Streaming Terrain for Modeling and Simulation, *The Interservice/Industry Training, Simulation & Education Conference*, Orlando FL, November 2011.