Converting One World Terrain Geospatial Content to CDB

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ABSTRACT

This paper describes an approach to reusing Synthetic Training Environment (STE) One World Terrain (OWT) content in both legacy simulators and modern real-time 3D engines using the CDB synthetic terrain standard. Synthetic terrain standards are important because having a shared understanding of the data representing the environment is necessary in order to achieve interoperability between simulation systems. A government funded project executed by Maxar and SimBlocks has resulted in a tool to convert existing One World Terrain content in the Well-Formed Format (WFF) into CDB. The Well-Formed Format is largely based on 3D Tiles, and both 3D Tiles and CDB are terrain standards adopted by the Open Geospatial Consortium (OGC). The generated CDB terrains for Fort Cavazos, Fort Irwin, and Joint Readiness Training Center (JRTC) have been approved and demonstrated in Unreal Engine 5 with WFF to CDB conversion metrics included. This paper will cover the benefits of the One World Terrain content, advantages and differences between 3D Tiles and CDB, lessons learned from developing the conversion tool, how the tool will be used by the government funding agency, and future recommendations.

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IMPORTANCE OF SHARED GEOSPATIAL CONTENT AND INTEROPERABILITY

Geospatial content development presents a significant challenge due to its high costs, time requirements for development, and limited applicability to specific devices and formats, which is only exacerbated by the increased demands for higher fidelity environments. Within the Department of Defense's (DoD) Modeling and Simulation (M&S) community, this issue is well-recognized, impacting data interoperability, continuity, shareability, and accessibility. As a result, the DoD frequently incurs additional expenses by repeatedly purchasing or recreating the same terrain data for different M&S systems over successive generations. The lack of effective communication and collaboration within the community exacerbates this problem, leading to a high risk of redundant efforts at the community level.

To effectively manage requirements at the community level and maximize reuse of geospatial content at scale, the Joint Staff has built and managed a standardized global repository of simulation ready geospatial data for use in Joint Training exercises within the Joint Staff's Joint Live Virtual Constructive (JLVC) Federation. The JLVC is the cornerstone platform for Joint Training exercises, and acts as the integrating backbone for Joint, Service, and Agency combat and functional simulations, with over 30 M&S applications supported in the federated environment. Each of these applications requires mechanisms to ensure fair and consistent performance across and between the network and data types. Specifically, for geospatial data, each M&S application often necessitates custom terrain development, demanding unique tools and specialized developers.

With the ongoing development of the Army's One World Terrain (OWT) program, there has been an increased demand within the Joint Training community to be able to leverage and integrate the growing set of OWT data and to promote reuse within the DoD per the DoD's Data Strategy goals and VAULTIS principles (U.S. Department of Defense, 2020). The tool described in this paper acts as the mechanism of parity. Allowing the Joint community to more effectively intake geospatial data for development and integration into Joint Exercises, reduce costs, and enhance operational efficiency. These efforts not only support the current and future needs of the DoD but will also create a more agile and responsive defense infrastructure.

LITERATURE REVIEW

A synthetic terrain is a virtual representation of a real-world location represented by surfaces, 3D models, textures, polygons, and other features creating a version of the world with a scaled-down fidelity such that it can be stored, manipulated, and by certain applications be simulated and rendered in real-time. Synthetic terrains have traditionally been developed as a dedicated database generation step utilizing customized tools and processes and then translated to different applications and subsystems, resulting in data duplication and loss of correlation (Lalonde, 2005).

Historically, due to limited computing resource constraints and competing requirements, different services within the Department of Defense chose non-uniform sets of terrain standards for their simulation training systems. Connecting these systems together after the fact can be very costly. For these reasons, previous efforts have examined existing terrain standards with the goal of consolidating on a smaller set of suitable standards for future simulation needs across the services (Chambers & Callaway, 2017). A terrain standard also may encompass many sub-standards, such as file formats for raster files, vector information, 3D model files, or texture files. These file formats may have been chosen for similar community or popular tool usage reasons, resulting in some cases in the same file formats used in different terrain standards, which at least provides some potential for commonality.

It is also important to consider that terrain databases may be frequently edited and may consist of many layers, so the terrain processing workflow should avoid losing information necessary for terrain modelers and terrain editing tools. The aforementioned terrain generation issues become exacerbated when collaborating with foreign governments who may not be given access to all the same data that is available to US organizations or may be restricted to using older versions of tools. Gougeat stressed this issue and the importance of standards through his work supporting SISO and the RIEDP standardization effort (Gougeat, 2018).

Terrain formats used within the simulation industry have not always arisen from top-down, well-designed processes within approved standardization bodies. In most cases they have been vendor-driven de facto community standards simply because they were the formats generated or consumed by the tools the organizations were using. This is certainly the case with the OpenFlight 3D modeling format, which is maintained by Presagis (CAE), going back to Multi-Gen Paradigm in the 1980s. The same argument can be made for the adoption of the proprietary FBX format due to the wide usage of Autodesk's 3ds Max and Maya. However, there are relevant standards bodies within the simulation industry that previously proposed or are currently maintaining geospatial format standards, such as the Simulation Interoperability Standards Organization (SISO), the Open Geospatial Consortium (OGC), Khronos, and the Metaverse Standards Forum. The OGC has approved the CDB (Common Database) standard and the 3D Tiles standard, which are both discussed in this paper.

Having a standard is not enough to generate adoption. Modifying existing applications and building new applications requires time and money, and a business case must be made as to why resources should be spent on standards support rather than other activities. One reason suggested for why CDB has been slow to be adopted was "a lack of software tools to read and write CDB" (Price, et al., 2009), for which Price described in technical detail how the Presagis Vega Prime application was modified to become a CDB Runtime Publisher. Several years later, Presagis released a plugin for Unreal Engine, V5D, capable of streaming CDB content that rapidly received attention in the simulation community (Presagis, n.d.). However, at the current time, there is disruption and uncertainty regarding the future of Presagis's product line after the announcement that Presagis would be folded into its parent company, CAE (Halldale Group, 2023).

Previous efforts have explored reusing Synthetic Training Environment (STE) One World Terrain (OWT) content in cooperation with the U.S. Army-led effort to collect and store world-wide geospatial content for simulation use cases. A One World Terrain integration with the Unity game engine has been demonstrated as part of Rapid Integration & Development Environment (RIDE) for research purposes (Hartholt, et al., 2021).

When evaluating an approach to geospatial content representation, one major design decision is determining which content will be stored as 3D meshes and which content will be stored as geospatial layers, which will affect both how the content can be edited, how the content will be paged and processed by a simulation application, and how graphical data can be efficiently rendered by a visualization application.

An alternative approach to 3D mesh content is to instead procedurally generate detailed content on visual systems by only transmitting a very small grammar representing each model. Blackshark.ai developed a capability to generate 3D content from satellite imagery and minimize data transfer to client devices using a custom grammar (Hollosi, et al., 2022).

The current effort has focused on offline conversion of geospatial content, but it would be possible to support streaming conversion capabilities in the future. Previous approaches to streaming 3D terrain content using alternative OGC XML-based web standards, including Web Mapping Service (WMS), Web Feature Service (WFS), and Web Coverage Service (WCS), were examined by Peele (Peele, et al., 2016). Foundation GEOINT 3D (FG3D) has also demonstrated modeling and simulation interoperability using CDB as the common terrain standard utilizing a microservices architecture with conversion capabilities to other geospatial formats. (Claphan, et al., 2021).

DESCRIPTION OF 3D TILES

The 3D Tiles standard was proposed by Cesium and adopted by the Open Geospatial Consortium has gained tremendous interest over the last several years due to its easily accessible Cesium Ion cloud service and its open-source integrations with web browsers and real-time 3D engines including Unity, Unreal, O3DE, and NVIDIA Omniverse. 3D Tiles largely leverages the glTF modeling standard from the Khronos Group and was designed to optimize streaming large amounts of geospatial content with high precision. Cesium also provides an online platform for content providers to distribute their assets in the 3D Tiles format. The 3D Tiles data is organized in a tileset, described as a JSON file (JavaScript Object Notation), containing a spatial tree subdivision of tiles with links to glTF models and various features and metadata, such as embedded geometric error, which may be used by runtime applications to select models at appropriate levels of detail based on calculated screensspace error (Lilly, 2024). The tiling is linked to varying levels of detail allowing visualization applications to only render pertinent data and models at a specific scale (Open Geospatial Consortium, 2021).

DESCRIPTION OF STE OWT

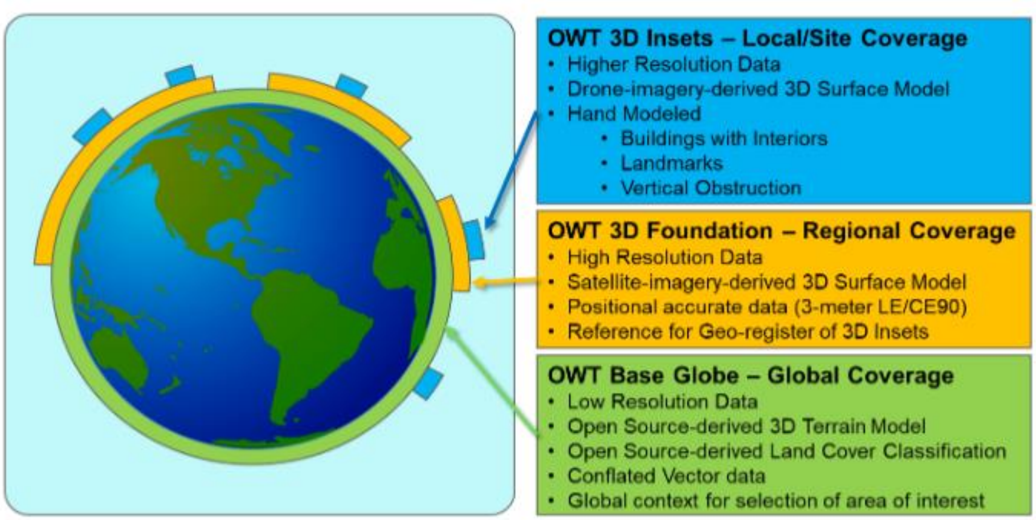
The Synthetic Training Environment (STE) has been developed to provide a multi-domain, interconnected training capability to allow for live, constructive, and virtual components to train simultaneously with the same terrain. Starting as a prototype in 2019, the STE vision was to leverage cloud technologies to provide high speed, point of need (PoN) training deployment to various locations and environments, along with traditional home stations. For this training, a single, global data source is desired to be made available for all DoD simulation and training programs to utilize for joint exercises and allowing "fair fight" between all units. The One World Terrain (OWT) Program was established as the backbone of STE to provide this capability. Through utilization of satellite imagery and automated photogrammetric processing, OWT generates 3D surface models (CE/LE90) and extracts data for applications in training and simulation as well as mission command operations.

For OWT, the 3D Surface Model, vector data (extracted and curated), land classifications, and art assets (3D models) are maintained and updated on the One World Server (OWS). Export of these components are in a STE 3D Terrain Pack in the Well-Formed Format (WFF). 3DTiles 1.1 and glTF 2.0 are the basis for the WFF. Features within the mesh are labeled in accordance with the U.S. Army's Ground Warfare Geospatial Data Model (GGDM) coupled with the National Geospatial Agency's (NGA) National System for Geospatial-Intelligence (NSG) Core Vocabulary (NCV) dictionary (Moore, 2022). It should be noted that the OWT Data Model can be extended to features and attribution outside the GGDM as needed based on training needs.

There are three stratums within the OWS: the Base Globe, the 3D Foundation Layer, and the OWT 3D Inset. These stratums are defined by feature and data resolution, with the Base Globe being the lowest and the OWT 3D Inset being the highest. The Base Globe is composed of open-source data within a 3D polygonal mesh. The imagery is 15-meter resolution while the elevation, land class, and bathymetry are 30-meter. Vector data is updated periodically and is in the OWT Data Model. Art assets for refinement of extracted data as well as models are bundled within the stratum. The 3D Foundation layer begins as a derivative of automated photogrammetric processing of satellite imagery. The imagery, elevation, and land cover are of 50 cm resolution, while the bathymetric surface is 15 cm. Extracted 3D structure models, such as building footprints and vertical obstructions, are also included. The remaining OWT 3D Inset exhibits 50 cm or better resolution of imagery, elevation, and land cover. This stratum is typically what is expected in a drone collection. Extracted 3D structure models as well as geospecific models are included.

The following figure provides high level descriptions of each stratum's characteristics (Figure 1; Moore and Toth 2024).

Figure 1. OWS Datum Stratums



A STE 3D Terrain Pack can include multiple stratums, defaulting to best available based on higher fidelity; however, the OWS provides users flexibility. For example, a MOUT site containing geospecific buildings with interiors can be stitched into the 3D Foundation Layer.

Within STE, OWT currently provides data in the WFF to the Training Simulation Software (TSS) and Training Management Tools (TMT) for runtime generation, currently VBS. The runtime will be hosted on a server for PoN federates; more specifically, the Reconfigurable Virtual Collective Trainer (RVCT), both Ground and Air (RVCT-Ground and RVCT-Air, respectively). Future use cases will include Soldier Virtual Trainer (SVT), Soldier Immersive Virtual Trainer (SiVT), Next Gen Constructive (NGC), and Live, Virtual, Constructive-Integrating Architecture (Moore, 2022). Conceptually, PoN users will be able to connect to the OWS for terrain exports.

DESCRIPTION OF WFF

WFF was developed out of the desire of the U.S. Army to have a global streaming terrain with a standardized data definition and the benefit of 3D Tiles' efficiency to render 3D mesh (Moore 2022). Currently, OWT provides terrain data in the WFF within specific areas of interest per PEO STRI direction, ranging in various terrain sizes and feature densities, to support the STE Program and its related exercises. 3D tiles can support various extensions and explicit tiling; however, through collaboration, Cesium and Maxar developed a schema and standardized data structure of most benefit to the OWT concept. The first is the extension of geoJSON (Geographic JavaScript Object Notation) to the format. This is to supplement the terrain with features and attribution not inherently rendered in the polygonal mesh. This includes features which support model placement, political boundaries, and/or other conflated sources which support the OWT Data Model.

WFF also utilizes implicit tiling. As OWT is a global source, this is necessary for clear definition of data organization as well as for supporting efficient querying of data as well as for instances where data updates may be desired. OWT uses S2 tiling which divides the globe into a hierarchy of quadrilaterals (cells) bounded by 4 geodesics. S2 has 6 root cells obtained by projecting 6 faces of a cube onto the globe (Maxar Technologies, 2024). This method of dividing up the globe is desirable in that it solves the issue of distortion the closer data requests are made near the poles. One example of such an issue is having to increase the size of topographic line map extents further away from the Equator.

The WFF dataset is contained within a .3tz file which is a zip file for larger quantities of 3D Tiles. The data is structured as tiles containing tile content such as 3D models, vector data, and child tileset. These components are bundled within a tileset.json. A STE Terrain Pack consists of these .3tzs (ex, buildings.3tz, water.3tz, roads.3tz), the tileset.json which references the .3tzs, an extent file, a manifest.json (files inside the terrain pack), and licenses. The work on potentially expanding allowable extensions and required metadata is ongoing with military and industry stakeholders.

DESCRIPTION OF CDB

CDB, previously known as Common Database, divides the earth into geocell tiles. Within each tile are layers of geospatial content, and tiles are subdivided based on the desired level of detail. CDB supports incremental updates to individual pieces of the terrain without requiring recompiling the entire database, and as an international standard, is not proprietary to any single vendor. Several of the formats used within CDB are OpenFlight for 3D models, TIFF/GeoTIFF for 2-dimensional raster files, ShapeFiles for vector data, and JPEG2000 for terrain imagery. The CDB standard consists of several large volumes that can be downloaded from the Open Geospatial Consortium website.

Several commercial vendors have products capable of exporting CDB content including Terra Vista from Presagis, TerraSim from Bohemia Interactive Simulations, and Trian3DBuilder from Triangraphics GmbH. The Joint Staff J7 developed a Terrain Generation Service (TGS), which enables synthetic terrain content generation using a web-based user interface (Chambers et al., 2017). Because previous versions of the TGS were architected in a way that led to stove-piped and stale data, J7 executed a successful technology refresh to transition to supporting CDB, several web-based geospatial standards, and other common file formats necessary for Joint LVC simulators (Chambers & Freeman, 2014).

While several proprietary image generators support CDB today, OpenSceneGraph with its complementary osgEarth terrain visualization is an open-source alternative capable of rendering CDB. (Linardos & Abbate, 2016) explained in detail how the CDB tiling structure maps to OpenSceneGraph's data structures. Some proprietary image generators had been based off OpenSceneGraph in the past, but OSG is not being updated frequently now. In recent years many vendors have moved away from solely using proprietary image generators towards showing applications utilizing the Unity and Unreal real-time 3D engines, with multiple vendors showcasing support for CDB in these engines.

ADVANTAGES AND DIFFERENCES BETWEEN TERRAIN FORMATS

The main differences between these specifications/standards are in the design goals. 3D Tiles targets web-based visualization while CDB is designed to be a single format that supports all aspects of a simulation in a high-end simulator environment. (I.E. visual, FLIR, radar, SAF, NVG). The extensions to 3D tiles provided by WFF tend to address the aspects of simulation content.

When it comes to the tile structure, both 3D Tiles and CDB organize their data into tiles based on latitude and longitude; however, CDB is more rigid in how it stores the data into tiles, layers, and LODs. Meanwhile 3D Tiles is more general with several ways that tiles can be defined and divided into smaller tiles, but the WFF extension to 3D Tiles enforces more consistency in how the tiles are organized.

PURPOSE OF WFF TO CDB CONVERSION TOOL

In the late 2010s, the Department of Defense's (DoD) Modeling and Simulation (M&S) community faced escalating challenges with maintaining and deploying vast amounts of geospatial content across an increasingly fragmented development landscape. In response, key DoD M&S community members implemented measures to enhance data reusability within the M&S community, selecting the Open Geospatial Consortium (OGC) CDB as the foundational open-source format for storage and export.

Converting multiple generations of federated simulations within the Joint Staff's Joint Live Virtual Constructive (JLVC) Federation into a single geospatial data format was impractical. Therefore, the Joint Staff developed export tools for CDB that are compatible with various JLVC-supported terrain formats and established a repository for CDB data generated from Joint Exercises. This repository now serves as the authoritative geospatial data source for the Joint Training community, allowing members to export high-resolution CDB data from previous exercises or a low-resolution global dataset into multiple simulation-ready formats. This approach further enables the Joint Staff terrain development team to update and reuse data for future exercises, significantly saving time and resources.

Meanwhile, there were growing concerns about the modernization of geospatial formats and the requirements for next-generation content, particularly with the launch of the Army's One World Terrain (OWT) project and the precursor to the Well-Formed Format, Well-Known Format. In 2017, U.S. Special Operations Command (USSOCOM), a major advocate for the CDB initiative, requested assistance from the Under Secretary of Defense for Acquisition, Technology, and Logistics (OUSD(AT&L)) hereinafter referred to as OUSD, and a Simulator Interoperability Senior Steering Group (SSG). In response, the OUSD issued a memorandum in 2018 titled: "Memorandum on Simulator Interoperability Issues Findings and the Way Ahead" (U.S. Department of Defense, 2018) based on the findings by the SSG. The memorandum urged the community to unify under a framework of interoperability for the disparate geospatial formats, ensuring that both formats co-evolved in alignment.

As Well-Known Format evolved into 3D Tiles derived Well-Formed Format, initial compatibility was assessed as sufficient by the availability of an open-source CDB to 3D Tiles (CesiumGS, 2024), but the reverse solution of 3D Tiles to CDB remained unachievable by interested parties until 2022 with an imperative to address fundamental training gaps within the Joint Training community. Between 2018 and 2022, the effectiveness of the interoperability memorandum diminished, yet the requirement for compatibility with the growing OWT program and the Joint Training community persisted. It was under this auspice that funding for the tool itself was finally allocated.

The creation of this tool significantly advances geospatial interoperability between the Army and the Joint Training community, fulfilling a key objective of the original 2018 OUSD memorandum. This development enables the Joint Staff to access OWT data for Joint Training Events and Exercises and to integrate this data into the Joint Staff CDB Repository. Moreover, it provides the Joint Staff's terrain development team with the capability to use Army OWT data as a baseline, enhancing the efficiency and effectiveness of their foundational terrain development for Joint Training exercises.

DESCRIPTION OF WFF TO CDB TOOL

The WFF to CDB Tool converts WFF version 1.6 to CDB version 1.2. Geographic areas of interest are selected from the STE OWT Interface and exported to WFF data on an external drive. A standalone machine will execute the WFF to CDB application converting the data from the external drive to a desired location accessible to the standalone machine. The WFF To CDB Conversion Tool provides a Graphical User Interface (GUI) to specify the WFF folder, CDB output location, and desired layers to be converted.

The WFF terrain is a 3D polygon mesh consisting of thousands of glTF models, which are converted into separate CDB layers for imagery, elevation, bathymetry, and raster materials within CDB's tile-based structure with support for levels of detail. WFF geospecific models, which are also in the glTF format, are converted into CDB geospecific models in the OpenFlight format. WFF features in the geoJSON format are converted into CDB network layers. Although earlier versions of CDB only supported Esri shapefiles for vector data storage and CDB 1.2 allows for either Esri shapefiles or GeoPackage, the requirement for this converter only included exporting to GeoPackage. OWT moving models in the FBX format are converted into CDB moving models in the OpenFlight format. The WFF to CDB Tool also supports CDB versioning, allowing subsequent updating of portions of a larger CDB through chaining.

The implemented feature sets allow for converting a wide variety of WFF content into CDB; however not all of the CDB layers are supported as features not currently present in the WFF datasets were de-prioritized. For example, geotypical models and external lighting systems are not handled in the current version of the tool.

TOOL USAGE BY JOINT STAFF J7

The Joint Staff began integrating the initial set of converted WFF data provided by the Army One World Terrain (OWT) into its CDB repository upon product completion in May of 2024. Initial data sets output by the project included three disparate regions within the continental United States that will be added to the current global coverage offered by Joint Staff's Terrain Generation Service and Joint Training Tool, which allow for the data to be used within Joint Exercises by the Joint Training community.

Future usage by the Joint Staff revolves around the ability to leverage the Army One World Terrain data from the final release (FY25) of the OWT Base Globe and 3D Foundation Regional coverage layers available on the One World Server (OWS) (Moore, 2022). The Joint Staff supports Tier 1 level exercises, National Level and Combatant Command Strategic and Operational Training Events, which demand large-scale geospatial data (Joint Chiefs of Staff, 2022). As such, the use of the 3D Inset layer may be limited, depending on the specific requirements of the supported Modeling and Simulation applications or exercise scope.

The Joint Staff's terrain development team will export OWT Well-Formed Format data at the geocell level from the OWS, converting it into CDB format. Once in CDB, the team customizes the data by adding or removing features to meet the needs of the Joint Live Virtual Constructive (JLVC) Federation and specific exercise requirements. The final CDB product, with the necessary modifications, will be stored in the Joint Staff's CDB repository for reuse by the terrain development team and the broader Joint Training community.

Initial use is to be derived by Joint Training exercise requirement. Joint Staff's terrain development team shall pull OWT Well-Formed Format data at the geocell level, if and as available, from the OWT OWS for conversion into CDB. Once in CDB, the terrain development team will add or remove features and functionality as needed to support the required geospatial formats present within the Joint Live Virtual Constructive (JLVC) Federation or needed by given exercise. The core CDB output product, with edited requirements, will then be placed in the Joint Staff's CDB repository for reuse by the terrain development team and Joint Training community.

TECHNICAL CHALLENGES

Most of the design and implementation went smoothly; however, the development team did encounter 3D moving model conversion issues, specifically related to incompatibilities when mapping FBX animations to OpenFlight degrees of freedom for articulated parts. We found varying 3D model designs from different sets of moving model asset sources would greatly impact potential software solutions. In retrospect we could have anticipated the difficulties we encountered in moving model conversions between FBX and OpenFlight. From a standards standpoint this probably should be addressed by the OGC CDB SWG since there is no longer a major software suite on the market directed at creating OpenFlight with the suspension of Presagis Creator. The techniques used in creating the FBX models are much more in line with the structures we find in game engines such as Unreal. However, the constructs used in creating these models did not contain the limits needed to constrain animations as we would expect in an OpenFlight model and for conversion implementation require specialized knowledge of those limitations encoded in the software.

CONVERSION PERFORMANCE

The conversion is reliably accurate when converting data, and the only performance issue is the time required to convert the database. Models and vectors (network layers) convert relatively quickly, but the terrain layers take much longer due to the processing needed to map the imagery pixels and convert the 3D WFF elevation into 2D CDB elevation. Over the course of the project, we made several performance improvements and added multithreading capabilities to utilize all of the available CPU processing cores. The performance times are limited by CPU processing capabilities, so running the WFF to CDB application on better hardware and with more cores will greatly speed up the conversion process.

A useful feature is that both the GUI and the command line applications have the ability to selectively convert only certain layers, so if the user desires to quickly convert new models without waiting hours for the terrain processing, the user can simply disable the terrain processing and the conversion will complete much faster.

The data conversion performance was highly dependent on a well-organized terrain mesh in the input data. We had three areas of WFF to consider: Fort Cavazos, Fort Irwin, and Joint Readiness Training Center (JRTC). While Fort Cavazos and JRTC conversions ran in an acceptable time frame (a few hours per geocell), the Fort Irwin database took much longer to convert. All of this extra time for Fort Irwin was found to be spent processing the elevation layer where we found that the Fort Irwin data had many issues with the terrain tessellation. In the end our fallback code built into the elevation process was able to correctly determine the elevation of each point, but the extra time required searching for the correct triangle due to the irregularities of the input grid became extremely significant.

In general the time to create network layers and GS Model layers are inconsequential to the overall time to convert the CDB. The major time considerations are the Imagery layers, Elevation Layer and Raster Material Layers. The processing times required to convert WFF to CDB are highly dependent on the hardware used to do the conversion. For the times listed here the conversions were done on a laptop system with an intel I7-13700HX processor (8 Performance cores - 8 Efficient cores) yielding 24 possible threads. (Hyper-threading enabled on Performance cores). The system had 32GB of Ram. Times for all three databases are shown in the table below.

Table 1. WFF to CDB Processing Times Per Layer

Database Layer	**Fort Cavazos**	**Fort Irwin**	**JRTC**
Network Layer	1 min.	1 min.	1 min.
Imagery Layer	1 hr 41 min.	1 hr 45 min.	43 min.
GeoSpecific Models Layer	24 min.	3 min.	10 min.
Elevation Layer	36 min.	8 hr 16 min.	10 min.
Raster Material Layer	58 min	1 hr 2 min.	21 min.
Total Time for Geocell	**3 hr 40 min.**	**10 hr 7 min.**	**1 hr 30 min.**

FUTURE RECOMMENDATIONS

The study of geospatial standards is a complex topic involving many technical challenges, but this is an exciting time with several ongoing disruptions in the modeling and simulation industry through the adoption of formats like 3D Tiles, One World Terrain, and CDB and the integrations with real-time 3D engines leading to new ways to access and visualize 3D content.

The Joint Staff J7's Joint Live Virtual Constructive (JLVC) modernization efforts require sustainment to both legacy simulations and integration of cutting-edge technologies across the Federation. This mission requirement, and the fragmentation of terrain formats across the subsequently supported simulations has continuously greatly taxed the ability for the Joint Staff to react to Joint Training exercise requirements. To meet the increasing demands for geospatial data going forward, mechanisms enabling interoperability and data continuity, such as the adoption of open standards and formats, and embedding reusability requirements into contracts, are essential. It is inevitable that more formats will be developed, that geospatial representation and technology to create it will continue to evolve, and that there is a balancing of requirements between what is current and what needs to be progressed. But future generations of the DoD's Modeling and Simulation (M&S) community development must not occur in a vacuum as it has in the past. Given the increasing requirements for the multi-Domain world we live in, the DoD should be coordinating next-generation development requirements from the ground-up with interoperability in mind for all aspects of the fight.

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