The OBW Emerald City Inset Experience

Ronald Moore	Thomas Kehr	Sean Sedlak	Ryan Boyd
Leidos, Inc.	CES, Inc.	Leidos, Inc.	Leidos, Inc.
Orlando, FL	Orlando, FL	Orlando, FL	Orlando, FL
ronald.g.moore@leidos.com	thomas.kehr@cesicorp.com	sean.p.sedlak@leidos.com	ryan.boyd@leidos.com

ABSTRACT

The Operation Blended Warrior (OBW) integration demonstration at the Interservice/Industry Training, Simulation and Education Conference 2017 (I/ITSEC'17) provided the U.S. Army an opportunity to evaluate the shareability of the SE Core Master Database by providing OBW participants with source data and correlated terrain datasets. SE Core and OBW'17 leadership selected a 200x300km area of the Pacific Northwest (PacNW) that met the land, sea and air requirements. SE Core prepared the PacNW dataset to meet the "DISTRIBUTION C" classification requested. During the first OBW planning meeting, the ground scenario group expressed the desire for a small inset representing a Dense Urban Terrain (DUT) area with unlimited distribution. A small 10x10 kilometer area of Seattle Washington, labeled the Emerald City Inset (ECI), was selected, and SE Core prepared this dataset to meet the "DISTRIBUTION A" request of the OBW leadership. After providing the initial production of a source dataset to all interested OBW participates, SE Core produced several run-time terrain formats to enable more participates to become part of the OBW ground scenario. SE Core provided both the PacNW and ECI source data to eighteen Government, Industry, and Academic organizations, while simultaneously generating multiple other formats including OpenFlight®[1], OneSAF, Virtual Battlespace 3 (VBS®[2]3), and Virtual Reality Scene Generator (VRSG™[3]) used during the OBW'17 demonstration events. Once the availability of an open-distribution SE Core DUT proliferated, many other Modeling and Simulation industry members outside of OBW'17 requested a copy for experimentation and demonstration at the I/ITSEC'17 conference. This paper describes the production processes and license coordination required to deliver the Distribution-C PacNW and Distribution-A ECI source dataset, along with the associated runtime databases. Additionally, this paper provides important lessons learned from the coordination across the various OBW'17 and general industry consumers and provides insightful feedback on what would have made the SE Core data more easily consumed by their respective products and processes.

Ronald Moore is currently the Chief Architect on SE Core CVEM. He has over 35 years of experience in the model, simulation and training industry with expertise in software development, computer graphics, computer image generation, simulation geospatial terrain database production, sound simulation, streaming audio and video, and PC and console game development. (18-EXEMP-0809-6962)

Thomas Kehr is a Senior Systems Engineer at Cole Engineering Services, Inc. Prior to this, Mr. Kehr served as the Director for the U.S. Army PEO STRI Training & Readiness Accelerator (TReX) where he assisted Government program offices develop streamline acquisition strategies for prototype development. Previously he served as the Integration and Test (I&T) Lead for the Synthetic Environment Core (SE Core) program at PEO STRI. Mr. Kehr holds two Masters of Science degrees from the University of Central Florida and is currently pursuing his PhD in Modeling and Simulation. Mr. Kehr is a Certified Modeling and Simulation Professional and a past member of the U.S. Army Acquisition Corps.

Sean Sedlak is a 10 year veteran of the training and simulation industry. He has held positions at AVT Simulation and is currently at Leidos. He is currently the gaming team subject matter expert for the SECore program having specialized in games for training for the last 8 years. Sean holds a degree from Full Sail University in computer animation.

Ryan Boyd is currently an Engineer on SE Core CVEM. He has over 15 years of experience in various DoD programs and has worked in the model, simulation and training industry for the past 12. He has expertise in software development, simulation geospatial terrain database production, systems engineering support for simulation training systems and terrain products integration support.

[1] OpenFlight is a trademark of Presagis Canada Inc. / Presagis USA Inc. within the United States / other countries.
[2] VBS is a registered trademark of Bohemia Interactive Studio within the United States and/or other countries.
[3] MetaVR and VRSG are trademarks of MetaVR, Inc. within the United States and/or other countries.

The OBW Emerald City Inset Experience

Ronald Moore	Thomas Kehr	Sean Sedlak	Ryan Boyd
Leidos, Inc.	CES, Inc.	Leidos, Inc.	Leidos, Inc.
Orlando, FL	Orlando, FL	Orlando, FL	Orlando, FL
ronald.g.moore@leidos.com	thomas.kehr@cesicorp.com	sean.p.sedlak@leidos.com	ryan.boyd@leidos.com

INTRODUCTION

The battlefield of tomorrow will not take place on the traditional regionally specific environment that has long been the standard for military training doctrine. Increasing global migration and rampant urbanization will lead to the development of densely populated dense urban terrain, often caller *megacities*, where armed groups will seek to exploit popular disaffection and weak governance (U.S. Army Training and Doctrine Command, 2010). Figure 1 provides an expert estimation on the rise of megacities as global population increases. By expanding its appreciation of megacities, the U.S. Army can better understand how units might operate within them as part of a joint, interagency, intergovernmental and multinational (JIIM) team. The process of building an understanding of dense urban terrain will be neither quick nor easy. Only through a methodical, relentless approach to appreciating complexity will the Army of the future be able to meet the demands put upon it (Chief of Staff of the Army Strategic Studies Group, 2014).

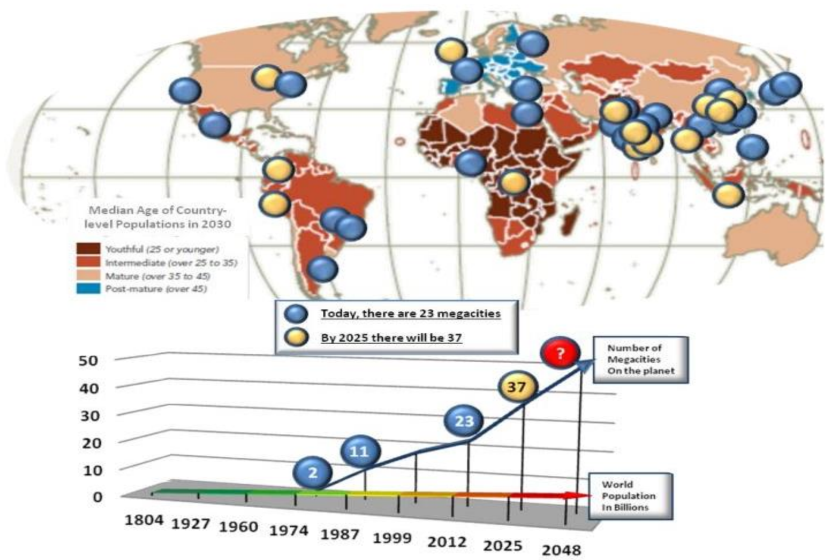

Figure 1. Global map showing the projected number of megacities as the global population increases through 2025. Source: United States Chief of Staff of the Army Strategic Studies Group http://www.army.mil/e2/c/downloads/351235.pdf

In response to this emerging threat of dense urban terrain, the military Modeling, Simulation, and Terrain (MS&T) domain faces the challenge of rapidly developing larger, more diverse, and more complex synthetic representations of natural environments necessary to facilitate military training. The MS&T community must position itself to provide the best available terrain representation, from geo-typical to geo-specific, based on authoritative data, while making use of innovative approaches in procedural terrain generation and sensor fusion to constantly improve the quality of the available global terrain. These dense urban terrain representations will need to include operational variables (Political, Military, Economic, Social, Information, Infrastructure, Physical Environment, and Time [PMESII-PT]) to fully represent the Operational Environment complexities. This paper illustrates a successful implementation of dense urban terrain integration across joint-simulation environment during the 2017 Operation Blended Warrior (OBW) exercise as part of the 2017 Interservice / Industry Training, Simulation and Education Conference (I/ITSEC).

BACKGROUND

Operation Blended Warrior was an annual event conducted at the I/ITSEC to explore the potential for Live, Virtual, and Constructive (LVC) capabilities to revolutionize training, education and testing for the defense and security sectors (NTSA, 2017). OBW seeks to answer important questions, such as: "What LVC capabilities need to be in the force?", "How will it enhance training?", "How much will it cost?", and "What are the challenges?" These questions are answered through direct Government and Industry collaboration on the I/ITSEC exhibit floor. OBW is not just a demonstration; it is research, requirements, testing and results analysis. For more information on OBW past and present, Mamaghani and Matthews provide a comprehensive summary of outcomes and feedback from 2017's OBW exercise (Mamaghani & Matthews, 2018)

As the lead service for I/ITSEC in 2017, the United States Army Program Executive Office Simulation, Training and Instrumentation (PEO STRI) challenged OBW participants with a series of objectives to achieve as part of the event. Several of these objectives focused on synthetic terrain, which has long been a persistent interoperability challenge for the MS&T community. Previous OBW events highlighted issues associated with synthetic terrain correlation, interoperability, and fidelity across simulation systems. After OBW 2016, participants recommended that a primary focus for OBW 2017 should be "integration of dense urban areas into terrain data, and improving database correlation and interoperability" (Hoke, Townsend, Giambarberee, & Schatz, 2017). In order to address this recommendation as well as forecast the need for growing synthetic terrain complexity to support next-generation capabilities such as the Synthetic Training Environment (STE), PEO STRI identified two terrain objectives to be investigated during OBW 2017:

1. **Multiple terrain providers / formats; integration of dense urban terrain:** One of the critical areas for the interoperability of heterogeneous simulation systems is the correlation of their terrain/environment data. Appropriate representation and use of dense urban terrain for various training tasks is a critical topic for the U.S. Army.
2. **Centralized distribution of authoritative data:** Maintaining data correlation is critical in a distributed simulation/computing environment. Use of a centralized network/cloud-based distributor of appropriate and authoritative data (e.g. Operational Environment) can facilitate wider application of operational training and improve data sharing and subsequently data correlation across the board. During some LVC events updates to specific data are required at run-time.

This paper focuses on Objective 1 identified above. For further insight into Objective 2, Woodman *et al.* provide a detailed analysis of the advanced centralized data repository process instituted for OBW 2017 (Woodman, Kehr, Mamaghani, & Sprinkle, 2018).

In order to properly posture OBW 2017 participants to achieve Objective 1, PEO STRI brought its full synthetic terrain capabilities to bear. The Synthetic Environment Core (SE Core) Government program office partnered with Leidos, Inc., the SE Core prime contractor, to provide two new terrain databases and a host of runtime formats to all OBW 2017 participants: The Pacific Northwest (PacNW) and the Emerald City Inset (ECI). These databases were provided in addition to the Southern California (SOCAL) database used during OBW 2016.

PACIFIC NORTH WEST DATABASE

In order to augment the SOCAL terrain database from OBW 2016, SE Core provided a large terrain database product from its Master Database (MDB), encompassing the PacNW geographic region of the United States. This terrain database was originally developed to support U.S. Army Home Station training as part of the Army Integrated Training Environment (ITE). The PacNW database provided OBW participants with an alternate feature set and terrain environment to conduct scenarios. SE Core did not provide any runtime terrain formats for PacNW. Instead, SE Core provided all the source data for this database, including feature data in Esri®[4] shapefiles, 3D models in OpenFlight and FilmBox (FBX®[5]) formats, imagery in GeoTIFF, and elevation in Digital Terrain Elevation Data (DTED) so that OBW participants could tailor their own products based on the needs of their systems. The SE Core PacNW database

---

[4] ESRI is a registered trademark of Environmental Systems Research Institute, Inc. within the United States and/or other countries.
[5] FBX is a registered trademark of Autodesk, Inc., within the United States and/or other countries.

was developed in accordance with the SE Core "Core Content" geospatial collection standard, which focuses on the collection of as much data and attribution as possible so that terrain correlation can be managed across simulation systems based on performance limitations. The PacNW database contained over 4TB of data.

The SE Core PacNW database was selected for a number of critical reasons. The first was that it encompassed an extremely large geographic area that could support the full-spectrum of military operations, to include land maneuver, air operations, and naval engagements. The PacNW represented approximately 240,000 square-kilometers and contains hundreds of thousands of geospatial features. Figure 2 illustrated the extents of the SE Core PacNW database. This database was also selected due to its inclusion of military bases from each of the three major military services: Joint Base Lewis-McChord (JBLM) (Army/Air Force), Naval Air Station (NAS) Whidbey Island (Navy), and Yakima Training Area (Army). The introduction of the PacNW database into OBW 2017 also attempted to address the dense urban terrain objective by providing three large cities, each containing vast amounts of feature data: Seattle, Portland, and Tacoma. Additionally, the PacNW database included features and 3D model assets for 23 Military Operation on Urban Terrain (MOUT) sites located at both JBLM and Yakima Training Area. Since this database was developed in support of the Army ITE, it also came packaged with tactical maps (CADRG) to stimulate military mission command systems.

The major challenge in releasing PacNW data to OBW participants was that the default distribution statement with all SE Core products is "DISTRIBUTION STATEMENT D: Distribution authorized to the Department of Defense and U.S. DoD contractors only." Since runtime formats were to be derived from the PacNW database by OBW participants and then displayed to the public on the I/ITSEC show floor, additional geospatial data manipulation had to be done to remove certain restricted data sources typically used by SE Core. This process is covered in greater detail in the next section. Ultimately, SE Core was able to expand the distribution of the PacNW database to "DISTRIBUTION STATEMENT C: Distribution authorized to U.S. Government agencies and their contractors" in anticipation that there may be non-DOD state and federal agencies that may have participated in OBW 2017.

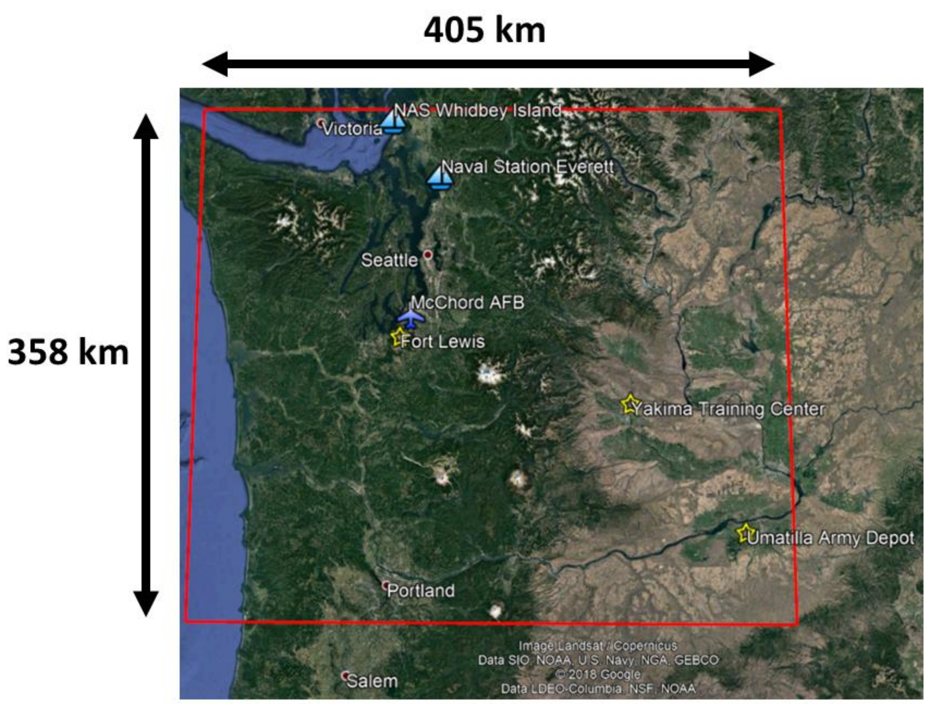

Figure 2. Size and extents of the SE Core Pacific Northwest database denoted by the red box

EMERALD CITY INSET

The Emerald City Inset (ECI) is a brand-new database developed specifically by SE Core in support of OBW 2017. ECI represents a dramatic technical achievement for the US Army and the MS&T community, through the development of an extremely dense terrain database and feature set which can readily be implemented across a wide variety of runtime terrain formats. The success of ECI at OBW 2017 marked a paradigm shift in the feasibility for developing feature-rich dense urban terrain databases for next-generation simulation and training platforms.

ECI comprises a 10-kilometer by 10-kilometer geographic area of downtown Seattle, Washington. ECI gets its name from being a high resolution 'inset' of the original PacNW database described in in the previous section. The overall extents of ECI are depicted in Figure 3. Since the SE Core "Core Content" specification was used to populate the ECI database, a vast amount of geospatial data was captured and made available. ECI contains approximately 86,000 unique geospatial features, including over 66,000 unique building features! A snapshot of the feature density of the ECI database can be seen in Figure 4. ECI data was further augmented with the use of SE Core's advanced synthetic imagery representation (Toth, Hale, Ramos, & Kehr, 2016).

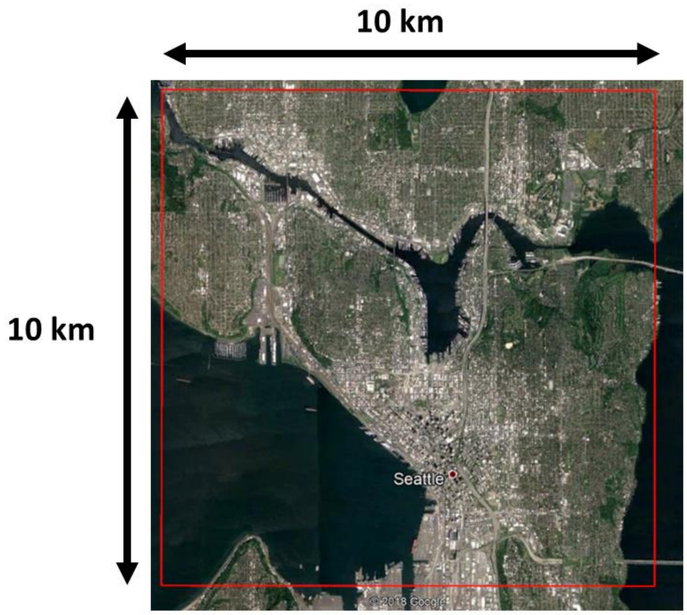

Figure 3. Size and extents of the SE Core Emerald City Inset database denoted by the red box

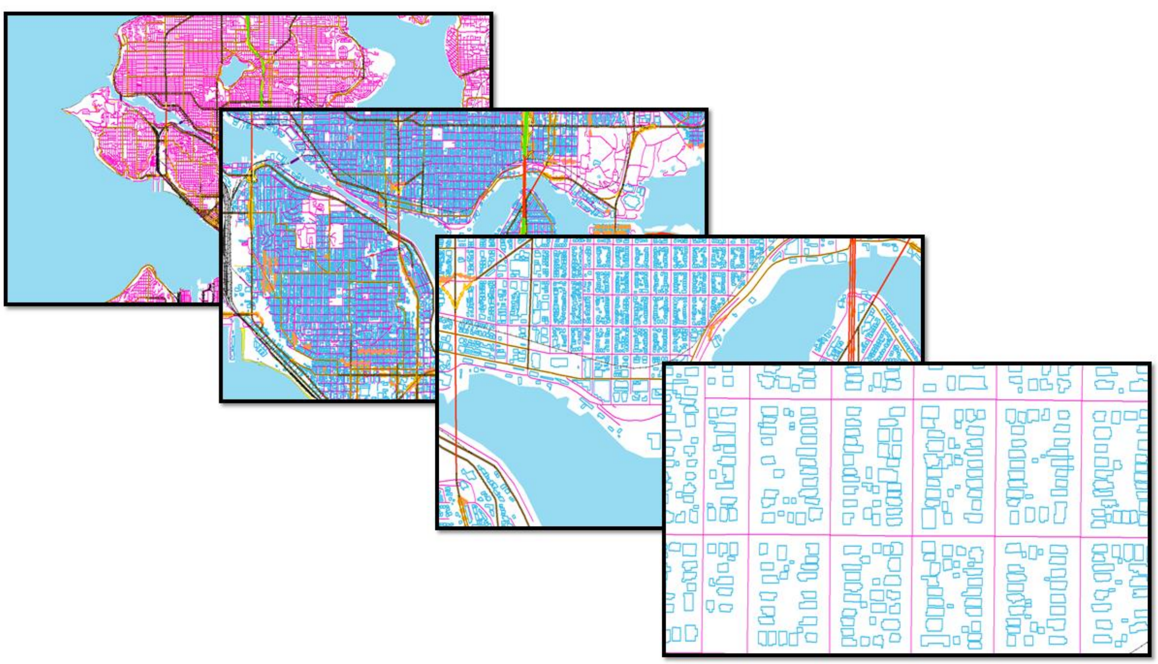

Figure 4. Example of geospatial feature density within the Emerald City Inset

ECI also provided OBW participants with the perfect opportunity to address the recommendation of using "commercial gaming capabilities to address training needs" (Hoke et al., 2017). In addition to data products, SE Core also developed runtime terrain formats and 3D model assets generated from ECI that were distributed to all OBW 2017 participants. SE Core was able to implement SE Core's Procedural Model Generation System (PMGS) on the ECI building feature data which was able to rapidly streamline the development of the ECI static model library and resulted in the development of over 30,000 unique and fully attributed models, some even included fully-functioning interiors (Eckman, Johnson, Moore, & Munro, 2015). A small representation of these procedurally generated models can be seen in Figure 5.

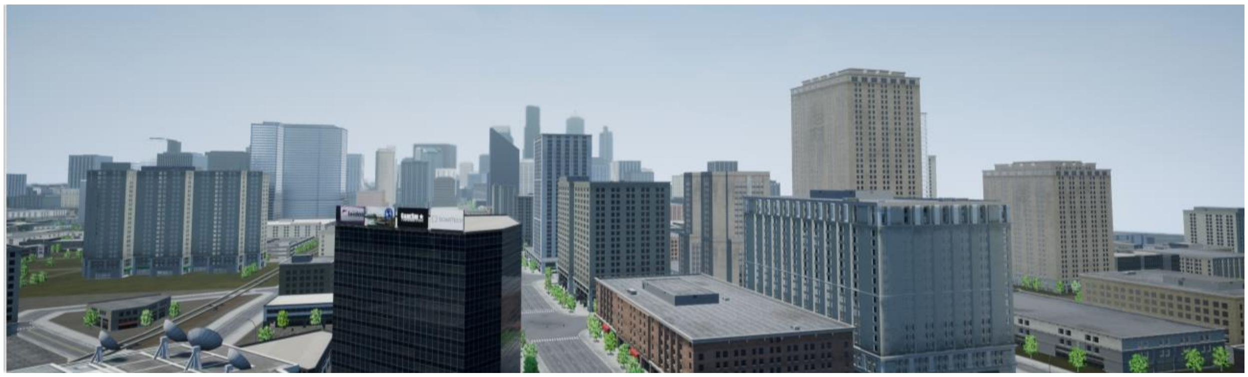

Figure 5. Emerald City Inset rendering in Unreal Engine 4 highlighting unique procedural model generation

One of the most powerful features of the ECI database was that it was the first SE Core database to be completely distributed as public release, or DISTRIBUTION STATEMENT A. This was not an easy task and ultimately required close coordination across a number of Government stakeholders and source data providers. Figure 6 illustrates the process by which SE Core was able to develop and distribute ECI as publicly releasable to OBW participants, regardless of affiliation or nationality. The first step in the security release process was to coordinate with the PEO STRI security office to understand the necessary approvals and documentation required for an Operational Security (OPSEC) review to release the database as "DISTRIBUTION STATEMENT A". Since ECI did not contain any sensitive information on DOD facilities or installations, the security office's guidance was to obtain approvals from each of the geospatial data providers that we used to conflate and derive the ECI database. This prompted us to conduct a full inventory and analysis of the original source data comprising the ECI to identify the source data provider and any distribution restrictions placed on the data from the provider. Three major data providers were identified as the basis for the majority of the ECI data: United States Geological Survey (USGS), National Geospatial Intelligence Agency (NGA), and the Homeland Infrastructure Foundation-Level Data (HIFLD). SE Core was able to successfully obtain release approvals from USGS and NGA on their respective data; however, HIFLD could not approve the release due to their data being marked as 'For Official Use Only (FOUO) and the sensitive nature of the data for homeland infrastructure. The HIFLD made up a significant portion of the building and road data comprising ECI, therefore SE Core was forced to find another source of data to fill the resulting data gap. ECI was ultimately augmented with data from OpenStreetMap (OSM)®[6], which proved to be extremely detailed in the downtown Seattle area of interest. Approval from OSM was not necessary due to their Open Data Commons Open Database License (ODbL) (OpenStreetMap Foundation, 2018).

Once all the necessary approvals were obtained, the SE Core Government office submitted them to the PEO STRI security office along with a memorandum of record attesting that ECI did not contain any data sensitive to national security. Once approved, SE Core was able to distribute ECI across the MS&T community without restriction. Due to the unlimited distribution restrictions, the ECI became a heavily requested SE Core product in preparation for I/ITSEC and OBW 2017. Between August and December 2017, SE Core filled 29 requests for the ECI data, with more having downloaded parts of it from the centralized OBW repository.

[6] OpenStreetMap is a registered trademarks of the OpenStreetMap Foundation, within the United States and/or other countries.

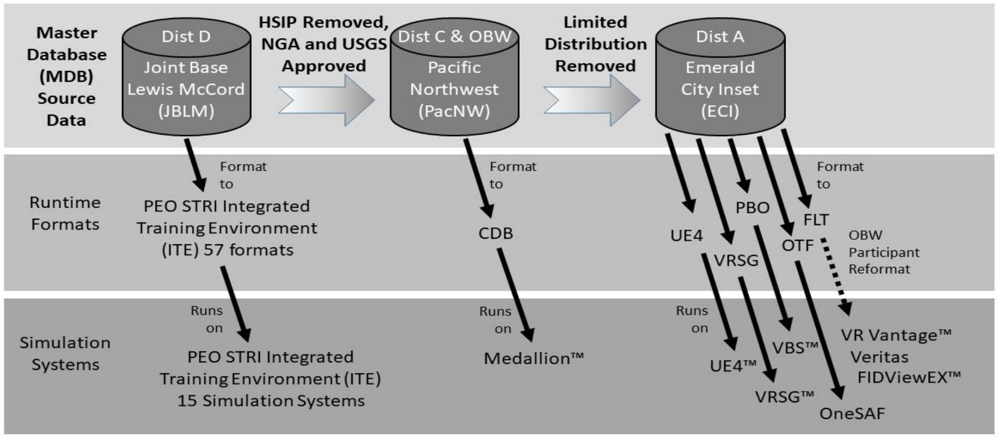

Figure 6. SE Core Emerald City Inset Generation and Distribution Process for OBW

EMERALD CITY INSET FORMATS AND DISTRIBUTION

SE Core's original intent was to only provide the underlying source data for ECI so that OBW participants could generate their own runtime terrain formats and tailor them to their specific Image Generators or OBW scenarios being developed. After several OBW planning meetings, it was recommended that SE Core generate several of the primary OBW runtime terrain formats, given SE Core's terrain generation expertise. This allowed OBW participants to focus on terrain integration efforts and scenario development. Several vendors ultimately used the ECI data to generate their own runtime products as well. Figure 7 illustrates the runtime formats that were generated from the SE Core ECI data as part of I/ITSEC and OBW 2017.

SE Core began by first generating the Virtual Battlespace 3 (VBS3) format of ECI since many of the OBW participants would ultimately use this format and it is a common format generated by SE Core as part of the Army ITE. The VBS3 ECI database took about 6 weeks to complete. Following the normal SE Core VBS3 process already put in place using TerraSim's® TerraTools®[7], building the ECI inset in VBS3 was pretty straight forward. A lot of data manipulation was needed to conform to the density of the DUT. SE Core's software team had to modify its road/terrain manipulation toolset to allow road and bridge connectivity in the highly dense and undulated terrain. Teammate GameSim®[8] provided heavy support to the manipulation of the GameSim PMGS software used to produce the unique procedural buildings in the ECI. While the SE Core database generation team handled running the database generation tools, the SE Core software team support allowed us to iterate numerous building sets over a short period of time allowing the highest quality models to represent correct building footprint heights and building types. Once the Vignette locations were chosen by the OBW participants, more data was digitized by SE Core to add realism such as street lights, mailboxes, trash cans, and many other scene clutter objects. Additional footage of the VBS3 Emerald City Inset can be found at: https://youtu.be/T4rTA-Ohr64.

Once the VBS3 format was completed, the SE Core team began to investigate the use of next-generation game engines to render the high-density content of ECI. An Unreal Engine 4 (UE4) ®[9] version of ECI was ultimately developed by Leidos using much of the same content and 3D assets generated for the VBS3 database. The UE4 database took approximately three-weeks to complete using GameSim's Conform tool. The ECI source data was converted into FBX format and imported into Unreal Engine. Using the UE4 sandbox editor, additions to the models and textures were made to liven up the scene. Real-time reflections and lighting make the scene more believable and realistic looking while being able to handle a lot more polygons than other outputs can handle. ECI was the first Unreal Terrain put together by Leidos and a lot of good lessons were learned to create more in the future. Additional footage of the UE4 Emerald City Inset can be found at: https://youtu.be/GxW4ssXkLAg.

---

[7] TerraSim and TerraTools are registered trademarks of TerraSim, Inc., within the United States and/or other countries.
[8] GameSim is a registered trademark of GameSim Inc. A Keywords Studio, within the United States and/or other countries.
[9] UNREAL, UE4, and UNREAL ENGINE are registered trademarks of Epic Games, Inc., within the United States and/or other countries.

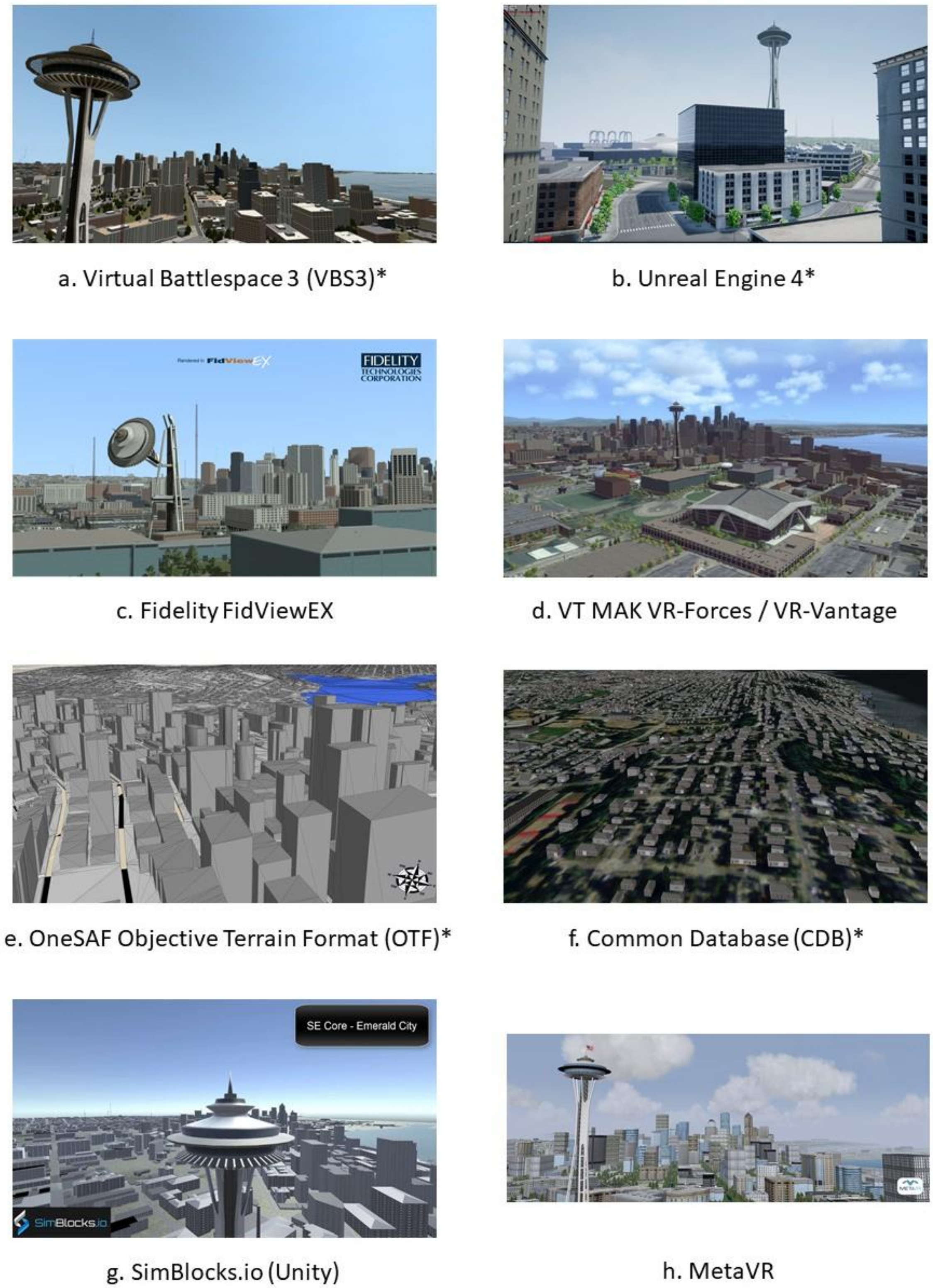

Figure 7. Several of the runtime terrain formats generated with the Emerald City Inset database, * Denotes a format built by SE Core or Leidos, Inc.

One unique activity performed in parallel to the development of the databases for the OBW I/ITSEC'17 demonstration was the development by Teammate CAE of a Common Database (CDB) version of the PacNW database. This activity was undertaken by PEO STRI to leverage the Distribution C and A datasets and provide insight into the sustainability of formatting and sharing SE Core data in the new Open Geospatial Consortium (OGC)®[10] CDB standard. The PacNW data was converted into CDB in under a week of effort. The PacNW data was then loaded and ran on a CAE Medallion Image Generator, as seen in Figure 7 frame f. Throughout the conversion process CAE identified changes that SE Core could do to the OpenFlight models that would make them directly convertible to CDB, including standardization in geometry organization, following more rigor in texture naming and using a common set of feature attributes.

SE Core built a MetaVR™ Inc VRSG terrain database that covered the extents of PacNW. The PacNW imagery and elevation were used while being supplemented with the elevation and models from ECI. This was the approach chosen for the high fly air support use case required.

SE Core produced an Objective Terrain Format (OTF) database using the ECI data. The build process was only modified to remove the multiple stacked highways which could not be elegantly mapped to routable transportation features due to time constraints. The OTF database was used for artillery simulation providing cover to the convoy as the scenario's blue and red forces interacted.

Several vendors were able to integrate ECI and introduce unique capabilities from their own image generators and systems. Fidelity Technologies Corporation was able to use the procedural and geospecific 3D assets from ECI to generate dynamic damage models for their ECI representation. An example of this can be seen in Figure 6c. They were also able to implement high-fidelity environmental light rendering directly to the ECI source models as seen in Figure 8.

VT MÄK also provided some unique enhancements to the ECI. They were able to efficiently incorporate the ECI source data into their VR-TheWorld®[11] global terrain server to be ingested by their VR-Forces® platform and VR-Vantage® rendering engine. This allowed VT MÄK to create geographically larger terrain database than the original ECI since they could easily supplement the original extents with data from their server. They were also able to supplement the ECI vegetation with more appropriate assets from their own repository. According to VT MÄK, they were able to integrate SE Core synthetic imagery and elevation into their VR-TheWorld server almost immediately, whereas the USGS sources were configured and conflated with existing VT MÄK USGS data. Finally, they were able to clip all the elevation and replace it with bathometric data in order to render dynamic ocean effects to support naval vignettes during OBW.

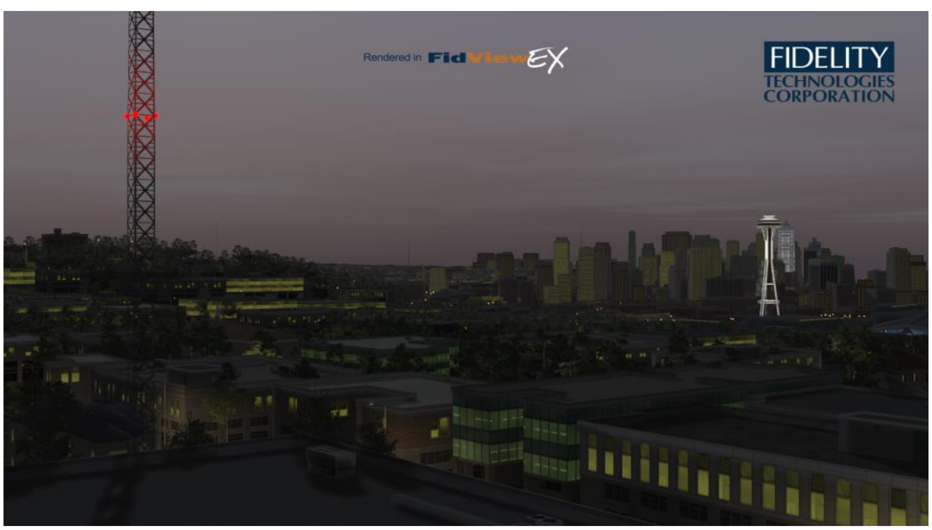

Figure 8. Fidelity Technologies rendering high fidelity lighting on the Emerald City Inset

---

[10] OGC is a registered trademark of Open Geospatial Consortium, within the United States and/or other countries.
[11] VR-TheWorld, VR-Forces, and VR-Vantage are registered trademarks of MÄK Technologies Corporation within the United States and/or other countries.

SimBlocks.io[SM12] implemented a process by which the entirety of the ECI database could be converted and processed into a Unity®[13] runtime in approximately 15 minutes. Their resulting runtime format which compresses the database is only a 57 MB file and is able to maintain high frame rates. More information on SimBlock's conversion of ECI to Unity can be found at: https://youtu.be/1ANgZHcWh7s.

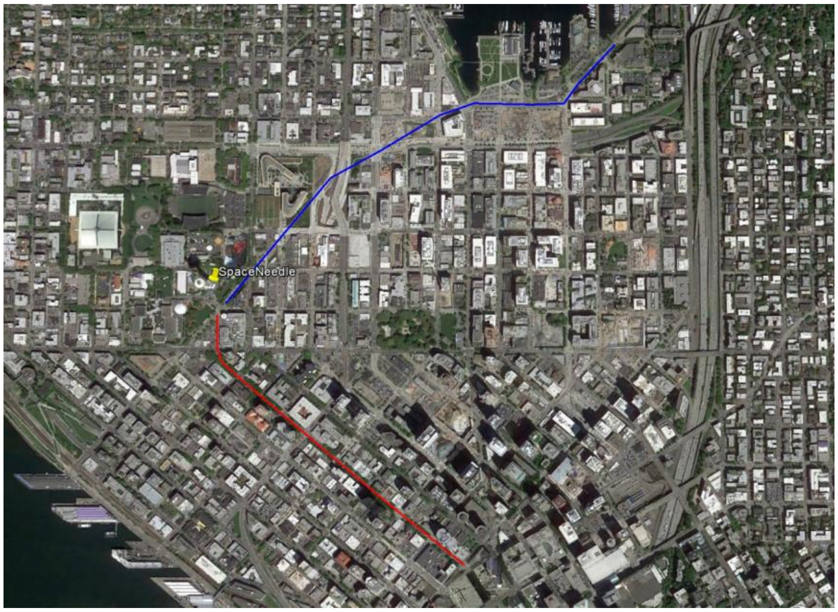

Figure 9. Convoy route used within ECI for OBW ground vignettes

EMERALD CITY OBW EXPERIENCE

SE Core received valuable feedback on the Emerald City Inset data during observation of OBW planning and execution as well as direct feedback from OBW participants who integrated the data. During the OBW planning processes, it was decided that ECI would primarily be used by the U.S. Marine Corps and Army for the ground-based vignettes. ECI offered the perfect environment to conduct convoy operations in an urban environment and demonstrate reactions to an ambush scenario. Figure 9 illustrates the ECI convoy route that was used for the OBW 2017 Ground vignette.

SE Core also received valuable feedback from other OBW participants on their own experiences using ECI throughout the OBW 2017 exercise and planning. SimBlocks used an OpenFlight format as a conversion starting-point to generate their Unity runtime format. The OpenFlight version of ECI was one of the last products developed by SE Core and was not provided to SimBlocks until about four-weeks prior to OBW execution. In this short time, they were able to develop a COTS plugin that supported SE Core data content in the Unity engine. According to SimBlocks, ECI was instrumental to helping them improve their OpenFlight conversion software. Prior to testing with the ECI, they did not have a robust solution to render the large number of buildings found in the database, but through testing and integration with the data they were able to develop a solution in time for OBW. Additionally, SimBlocks was able to greatly improve their software's memory management to handle other large databases appropriately. As first-time participants in OBW, SimBlocks received the ECI and the OBW Southern California (SOCAL) database at about the same time. These databases were larger and denser than any previous OpenFlight databases they had tested. Their lean engineering team had to work through significant time and resource constraints to successfully showcase the Emerald City Inset in addition to preparing for other I/ITSEC demonstrations and activities. At I/ITSEC, SimBlocks demonstrated a small area of ECI, but ultimately showcased the SOCAL database since their strategic I/ITSEC message was focused on supporting large geographic areas.

[12] SimBlocks.io is a service mark of SimBlocks, LLC within the United States and/or other countries.
[13] Unity is a registered trademark of Unity IPR ApS within the United States and/or other countries.

For the OBW ground vignettes that VT MÄK supported, they found that the SE Core ECI geo-typical and geo-specific models were high quality, very detailed, and made for visually appealing up-close views during simulated ground operations. VT MÄK was able to integrate most ECI features within a few hours. Some features they uploaded to the VR-TheWorld server were accessed directly by their VR-Forces simulation engine. For those features to be visualized, they merged them with their existing procedurally-generated OpenStreetMap-based buildings. This required setting up masks between the OSG data and the SE Core models. This required multiple iterations to balance good frame rates and acceptable load times with the SE Core models. VT MÄK replaced several features with VR-Vantage specific models, rather than SE Core OpenFlight models. This was primarily done for trees, since VR-Vantage contained more realistic SpeedTree®[14] models.

During integration efforts, VT MÄK found that the SE Core procedurally generated building models were very large and that loading tens-of-thousands of individual SE Core OpenFlight models was not very efficient for their image generator. They also found that the SE Core models contained a VBS-specific bounding box, which added unnecessary extra data that needed to be loaded and subsequently stripped away in order to avoid visual rendering artifacts. VR-Vantage also didn't support some of the specialized effects textures of the SE Core procedural models, so they had to update their OpenFlight loading capability. VT-MÄK ultimately ended up pre-processing the data to remove the VBS-specific data and adjust the Level of Detail (LOD) ranges to improve performance.

The SE Core produced MetaVR Inc. VRSG database required a few modifications to render at an acceptable framerate. It was determined that all of the ECI unique buildings could not be rendered without visual anomalies. To mitigate this, SE Core used simpler visual models generated from SE Core's PMGS software. These models were much simpler with regards to triangle count and texture references. To keep the highest visual fidelity possible the vector data was modified to use the simpler visual models for the city but supplemented with the high-resolution gaming models for the convoy routes. The balancing of model fidelities enabled the runtime to hold an acceptable framerate.

LESSONS LEARNED

SE Core uncovered several lessons learned about ECI and data distribution in general during the planning, integration, and execution of OBW 2017. One of the most obvious and important lesson learned was the timely distribution of data to participants. Due to unexpected engineering workload in making ECI a "DISTRIBUTION A" data product along with the increased responsibility of developing ECI runtime terrain formats, SE Core was not able to release the initial ECI data products until mid-October 2017 – approximately six weeks before OBW execution at I/ITSEC. Providing the ECI database earlier would have allowed development teams more time to investigate if any significant engineering work would be required to properly handle the data. This was especially true for small-business participants without large pools of engineering resources. Additionally, the compressed time-line meant that SE Core continued to refine the ECI database after the initial release, which caused some confusion among OBW participants as they struggled to integrate the database in time for the event.

Configuration Management (CM) and distribution of the ECI data also posed a significant challenge. The original intent was to host the entirety of the ECI database on the centralized OBW repository jointly developed by PEO STRI and Leidos. File size limitations of the Amazon Web Services (AWS)®[15] S3 cloud, prevented SE Core from hosting a significant amount of the ECI data, which meant that OBW participants could not download it on demand. Instead, SE Core leveraged their traditional CM processes to ship and hand-carry disk drives containing the ECI and PacNW data to participants and vendors. This posed a significant strain on SE Core CM personnel and ultimately delayed delivery of ECI. The file size limitations of the repository were ultimately resolved, but not until after OBW was completed. In support of future events, one solution would be to prepare a large number of data deliveries ahead of time and distribute them as needed in order to reduce delivery lead times. On the positive side, the Distribution A release approval meant less paperwork for vendors to complete prior to requesting delivery. Woodman et al provides additional information and lessons learned on the OBW 2017 centralized data repository (Woodman et al., 2018).

[14] SpeedTree is a registered trademark of Interactive Data Visualization, Inc., within the United States and/or other countries.
[15] Amazon Web Services is a registered trademark of Amazon Technologies, Inc. within the United States and/or other countries.

SE Core also identified challenges when providing static 3D models to other vendors. Since many vendors do not leverage the VBS-specific data within SE Core models, it was recommended that SE Core turn this data off by default when sharing models. Vendors also requested more extensive use of shared texture atlases to improve rendering performance. Several OBW participants found referencing the large number of procedural OpenFlight models provided by SE Core to be inefficient when loading large geographic areas. It was recommended that SE Core share their LOD optimization strategy for the large number of models so that participants did not have to develop their own approaches. A recommended approach was for SE Core to advertise the procedural algorithms and tools for how the models were generated (i.e. attributes, randomness factors, and specific mappings for structures, roof clutter, and textures) along with the textures and art assets used for the buildings. An alternative solution to this is to distribute PMGS to participants along with the configurations used to generate the procedural assets for the terrain. This may have enabled participants to better manage database load and resulted in better overall system performance.

CONCLUSION

The development of an extremely dense urban terrain environment with a "DISTRIBUTION A" release statement significantly contributed to the success and quality of demonstrations during OBW 2017. Along the way, the SE Core team learned critical information regarding the development of high-density datasets and runtime terrain formats; this knowledge came from the team's development and integration effort, along with collaboration and input from other Industry stakeholders. The Emerald City Inset has transcended the confines of just OBW and will continue to be a demonstration and testing asset for the modeling, simulation, and training community. Already, several Industry partners have begun using ECI for purposes beyond OBW and I/ITSEC. After making additional updates, companies like VT MÄK are including ECI as a supplemental data package available for their products. Other companies, such as SimBlocks, have used ECI as a central part of their technology demonstrations to highlight innovative capabilities and compete for emerging opportunities, such as the Army's Synthetic Training Environment (STE).

SE Core will continue to maintain and improve The Emerald City Inset as needed and continues to experiment across additional next-generation rendering technologies. Due to the success of ECI, SE Core is investigating developing additional "DISTRIBUTION A" data products to be shared across the MS&T community. In the meantime, ECI will continue to be available for distribution by the Army's SE Core program.

REFRENCES

Chief of Staff of the Army Strategic Studies Group. (2014). Megacities and the United States Army, (June). Retrieved from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwijl9DksaXMAhUIWCYKHZxYBBgQFggcMAA&url=http%3A%2F%2Fwww.army.mil%2Fe2%2Fc%2Fdownloads%2F351235.pdf&usg=AFQjCNEmW6G9O33Cbg9FryOhySNFe9yIow&sig2=poJiUSSoLEk-vv_2eW48aA

Eckman, S., Johnson, M., Moore, R., & Munro, J. (2015). Automated Modelization in Terrain Database Production. In *Proceedings of the 2015 Interservice/Industry Training Systems and Education Conference (I/ITSEC)*. Orlando, FL.

Hoke, J., Townsend, L., Giambarberee, S., & Schatz, S. (2017). Performance Measurement in LVC Distributed Simulations: Lessons from OBW. *Proceedings of the 2017 Interservice/Industry Training Systems and Education Conference (I/ITSEC)*, (17207), 1–11.

Mamaghani, F., & Matthews, C. (2018). Operation Blended Warrior 2017 - Behind the Curtain! In *Proceedings of the 2018 Interservice/Industry Training Systems and Education Conference (I/ITSEC)*. Orlando, FL: NTSA.

NTSA. (2017). Operation Blended Warrior. Retrieved July 6, 2018, from http://exhibits.iitsec.org/2017/public/Content.aspx?ID=35035&sortMenu=109000

OpenStreetMap Foundation. (2018). Copyright and License. Retrieved August 6, 2018, from openstreetmap.org

Toth, R., Hale, J., Ramos, P., & Kehr, T. (2016). Aerial imagery. In *Proceedings of the 2016 Interservice/Industry Training Systems and Education Conference (I/ITSEC)*. Retrieved from http://wiki.openstreetmap.org/wiki/Aerial_imagery

U.S. Army Training and Doctrine Command. (2010). *The United States Army Operating Concept 2016-2028*. Retrieved from http://www.tradoc.army.mil/tpubs/pams/tp525-3-1.pdf

Woodman, M. D., Kehr, T. W., Mamaghani, F., & Sprinkle, R. (2018). Operation Blended Warrior 2017 Terrain Database Interoperability Lessons Learned. In *Proceedings of the 2018 Interservice/Industry Training Systems and Education Conference (I/ITSEC)*. Orlando, FL: NTSA.