

**United States Military Academy
West Point, New York 10996**

**A Multiresolution Experiment to Enable
Impacts of High Fidelity Environments on
Unmanned Ground Vehicle Representation**

**OPERATIONS RESEARCH CENTER OF EXCELLENCE
TECHNICAL REPORT #DSE-TR-0912**

DTIC #: ADA500534

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Professor and Head, Department of Systems Engineering

June 2009

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Abstract

Geospatially enriched synthetic environments are needed for development and assessment of unmanned ground vehicle (UGV) performance to support sensor fusion and sense making. This work will address how the high-fidelity/resolution environment is achieved and integrated to inform simulations addressing critical questions. We will investigate a multi-resolution modeling capability to inform development of a high-fidelity synthetic environment (HFSE) testbed and to link to other models and simulations. This report will discuss results and lessons learned in developing an engineering- and operational-level experiment for proof of concept.

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Chapter 1: Introduction

Ground robotic systems are integral components of the current and future forces, integrated across a variety of missions including reconnaissance, search and detection, fire support, force protection, and logistics. As advancements are made along the spectrum toward the goal of autonomous navigation, enriched geospatial synthetic, or simulated, environments can provide a means to assess system and subsystem performance. Providing such environments will promote commonality and comparison of experimental results, will reduce costs, and will speed development.

The U.S. Army Engineer Research and Development Center is leading an effort with partners, including the United States Military Academy (USMA), to create a high fidelity synthetic environment (HFSE) testbed to support development of unmanned ground vehicles (UGV), including engineering- and operational-level capabilities. Engineering-level capabilities focus on system and subsystem performance where as operational-level capabilities are at higher echelons and include examining contributions of UGV systems to an operational mission.

A stakeholder analysis was conducted (Goerger, Moore and Nagle, 2008) and identified the need for a HFSE to facilitate UGV performance simulation and analysis, particularly in the areas of mobility, obstacle and target detection, and navigation. Stakeholders' needs for a HFSE are summarized as the following: (a) interfaces or integration that are simple to achieve and will not require retrofitting or reprogramming; (b) near-real-time run-time performance; (c) support exercises and experiments, and (d) good visual representation and correlation.

Based on the results of the stakeholder analysis, an integrated decision analysis framework was developed to assess HFSE testbed design alternatives (Goerger et al. 2008). The decision framework linked functionality parameters, value models, and metrics to generate and assess design alternatives. Assessing how well the HFSE supports stakeholder values regarding ease of interfaces/integration, run-time performance, support to exercises and experiments, and visual representation is the key to the development of a HFSE.

To inform development of a HFSE testbed and to link to other models and simulations, a major thrust of the effort presented in this report consists of developing and conducting experimental- and operational-level experiments. This report describes the experimental environment, or testbed, that was created and the experiments conducted to investigate means of meeting stakeholders' needs and collects lessons learned.

1.1 Background

In 2006, the Office of the Secretary of Defense (OSD) Joint Ground Robotics Enterprise (JGRE) funded the development of the Virtual Autonomous Navigation Environment (VANE). A stakeholder analysis and needs analysis was conducted and an initial set of use cases were developed. This project takes the information that was gained during these projects and applies it to the development of a multi-resolution synthetic environment to facilitate the assessment of UGVs in a high fidelity synthetic environment.

1.2 Use Case Development

To help guide the experimentation process in the development of an HFSE, an initial set of use cases was developed (Nagle, Goerger, and DeLong, 2008). The use cases were based on an analysis of critical capability gaps identified in the U.S. Army/U.S. Marine Corps Ground Robotics Master Plan (GRMP) (Robotics Systems Joint Project Office (RS JPO), 2007).

In Nagle et al. (2008), a use case was described as a specific scenario, or vignette, in which a UGV is employed to contribute to a mission. It is a narrative description of a sequence of actions a war fighter equipped with a UGV, would undertake to accomplish a goal. The Use Cases developed do not identify requirements, but rather imply them in the stories they tell, leaving it up to an analyst to identify the requirements. The use cases avoid identifying or describing specific platforms, but rather create opportunities for analysts to identify capabilities. The capability requirements derived in this manner provided a valuable supplement to UGV capability gaps assessments which are explored through a series of experiments.

The experimentation process is two-fold. First, a UGV experimental testbed is created and evaluated through an engineering-level experiment based on the stakeholder analysis completed with respect to the HFSE while applying a derived use case. There were several recommendations from the stakeholder analysis as detailed in Goerger, et al., 2008. Each of these recommendations is taken into consideration during the development of the UGV experimental testbed

Second, the UGV experimental testbed is used to evaluate the use case for the operational-level experiment in order to demonstrate the capabilities of the testbed with

respect to the actual performance of the UGV given the use case in the HFSE. For this experiment, Use Case #1 - Locate Possible Enemy Improvised Firing Point/Device, is utilized to demonstrate some basic engineering-level capabilities and operational-level UGV functionality within the testbed. Measures of effectiveness were developed for the purpose of assessing both the engineering- and operational-level UGV experimental testbed given the Use Case #1.

Chapter 2: Experimental Overview

Figure 1 depicts the approach and outcomes, or products, for the HFSE requirements and design analysis conducted in FY07 and FY08. The approach involved conducting a stakeholder analysis, developing a value hierarchy and model, generating and assessing the HFSE design options using the value model, and conducting experiments to demonstrate the HFSE potential and proof of concept. The stakeholder analysis gathered information on issues and the needs of stakeholders. Thus, as a foundational part of the development of the HFSE, a literature review was conducted and a series of interviews and collaborative sessions with stakeholders were used to elicit information pertinent to its functionality. This led to the generation of a framework for assessing the HFSE architecture and design that mapped needed HFSE functions to value measures. Use Case development provides a focus for scoping assessments and supports experiments that develop the HFSE within the stakeholder community. The constraints, limitations, and assumptions for the analysis are detailed in Nagle, et al., 2008.

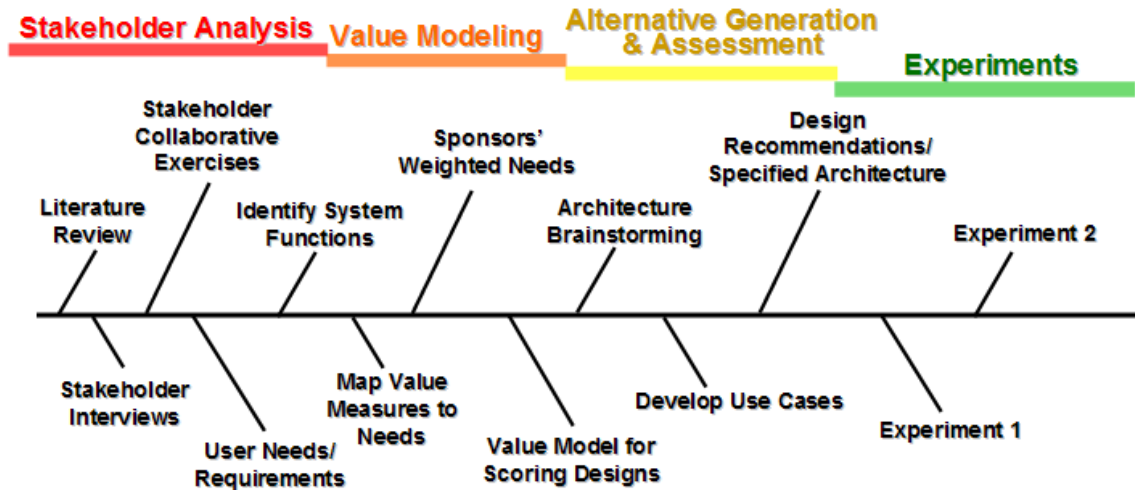


Figure 1. Tasks and products for the high-fidelity synthetic environment (HFSE) requirements and design analysis.

The next step for this project was to take what was learned as a result of the stakeholder analysis and develop the UGV HFSE testbed in order to evaluate the capability as well as evaluate the potentials in using this environment for UGV assessment. Chapter 3 details how the UGV HFSE testbed is developed and the characteristics of interest that were used during this development process. Chapter 4 details Use Case #1 and the scenario developed to assess the environment and the UGV performance. Chapter 5 assesses the testbed environment in an engineering-level experiment and Chapter 6 assesses the UGV performance in the environment in an operational-level experiment. Chapter 7 summarizes the results of this work and Chapter 8 addresses future work to be done in this area.

Chapter 3: UGV HFSE Testbed Development

The results of the stakeholder analysis identified the key functions needed to assess UGV in the HFSE. Figure 2 depicts the functions and sub functions identified during the stakeholder analysis.

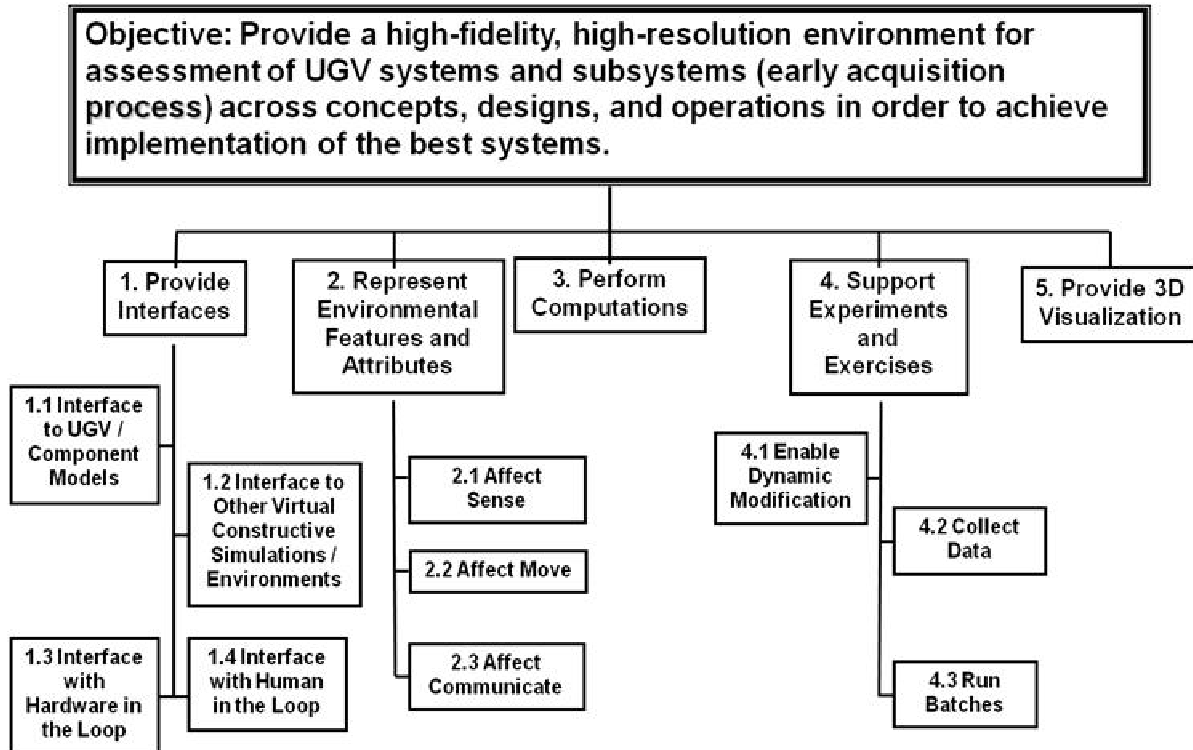


Figure 2. Functional analysis of the unmanned ground vehicle high-fidelity synthetic environment testbed.

These functions led to the identification of the necessary functions within the testbed as well as the metrics in which to measure the capabilities of the testbed. The development of the UGV HFSE testbed centered on using the ERDC model Autonomous Navigation Virtual Environment Laboratory (ANVEL) for the high-fidelity UGV representation and the Army simulation One Semi-Automated Forces (OneSAF) as the operational level driver. This model and simulation are connected via High Level Architecture (HLA) software provided by the Modeling Architecture for Technology and

Research Experimentation (MATREX) products (Hurt et al. 2006). OneSAF is also the operational level driver for TRADOC experimentation and is at the core of the Battle Lab Collaborative Simulation Environment (BLCSE) Federation (DeLong, 2005). The BLCSE Federation utilizes MATREX to facilitate its HLA environment. Given the large number of stakeholders familiar with this proven environment, it is a natural conclusion to bring ANVEL to this environment where the benefits from this research will be far reaching not just as a proof of principle but also to help stakeholders to start experimenting and assessing UGV performance in order to further their research goals.

3.1 ANVEL Overview

ANVEL is a rigid-body, physics simulation specialized for high-resolution, real-time mobility modeling of wheeled and articulated platforms. Its purpose is to represent mechanical system interactions with realistic movements while providing interfaces for mechanical systems and sensor models. ANVEL also facilitates an easy configuration of mission scenarios. The ANVEL architecture is described as open computing framework with vehicle/object modeling, rigid body dynamics simulation, actuator modeling, terrain generation and a ground contact interface. ANVEL allows for the simultaneous viewing of sensor output, vehicle mobility and Autonomous Navigation System (ANS) and features a mission rehearsal and playback function. ANVEL is being developed for compliance with the Joint Architecture for Unmanned Systems (JAUS) which is one of the stakeholder recommendations.

Additional benefits of ANVEL are the interaction with guest JAUS compliant subsystems, faster debugging of components due to the modularity of the ANVEL code

and various viewing options for output data. Figure 3 shows the high resolution graphics\scene quality capability within ANVEL.



Figure 3. ANVEL Graphics.

3.2 OneSAF Overview

OneSAF¹ is a U.S. Army constructive simulation that was developed to reduce the number of simulations and encourage interoperability and reuse while meeting the requirements to model and simulate the next generation force requirements. OneSAF is a composable, platform-independent, entity-level Computer Generated Forces (CGF) simulation for a brigade and below sized unit, down to the individual combatant, and is capable of stimulating virtual and live simulations. OneSAF composition tools include entity, unit and behavior. OneSAF has the capability of representing multiple forces and relationships. Relationships between forces are changeable\asymmetric and are portrayed as friendly, hostile, suspect, and neutral. Some crowd modeling is available. OneSAF

¹ <http://www.onesaf.net/community/>

models the contemporary operating environment to include improvised explosive devices (IEDs), mouse hole creation, dynamic side changes, reduced profile shooting, detection of vehicle borne IEDs, indirect fire weapons used as direct fire weapons, urban operations MEDEVAC, sniper tactics, penetration of building walls, conduct raids, controlled mines, ambush and shield tactics, expedient field fortifications, decoys and rocket and mortar attacks.

OneSAF represents the full range of Battlefield Functional Areas (BFA), systems and operations, semi- or fully-automated behaviors, multi-resolution, validated models, multi-resolution terrain, ultra high resolution buildings, two-way connectivity to Command, Control, Communications, Computers and Intelligence (C4I) devices. It also has data collection and after action review tools.

3.3 MATREX Overview

MATREX facilitates the integration of models and simulations with multiple fidelity levels in a distributed environment, for the purpose of experimentation and analysis. The benefits of the MATREX environment is that it enables the reconfiguration and reuse of components for engineering model development and evaluation, technology tradeoffs, capabilities assessments, concept development, experimentation and testing, and supports decision making over the entire acquisition lifecycle.

MATREX is an architecture based on services that “exchange object data through a runtime infrastructure” (Hurt, McDonnell and McKelvy, 2006). Interoperability includes HLA RTI 1.3NG, IEEE1516, TENA 5.4, and DIS FY08. The primary elements of MATREX are the architecture\environment, model and simulations, tools, interoperability and collaboration features. MATREX is advancing simulation

technology, infrastructure and processes to enable better informed decision making. MATREX provides many of the tools and methodologies to help reduce technical costs and schedule risk. (Hurt, et al., 2006.)

Chapter 4: Experiment Scenario Development

4.1 Overview

Use cases are developed in the most general terms, and are meant to broaden the spectrum of considered capabilities and technology enablers for UGV. The use cases are intended to be generic with no focus on a particular foreign country or group of people. The use case timeframe is applicable for current and future forces through 2032 as identified by the Office of the Secretary of Defense's Unmanned Systems Roadmap 2007-2032 (Office of Secretary of Defense, 2007). This experiment focuses on the employment of use case #1—Locate possible enemy improvised firing point/device (Nagle, et al., 2008). Maneuver, search, detect and locate tasks underlies this Use Case.

4.2 Use Case #1: Locate Possible Enemy Improvised Firing Point/Device

Units conducting counter-IED operations which consist of UGV are employed to identify IED and firing points using the functional threads of maneuver, search, detect, and locate while conducting route clearing operations. Table 1 describes use case #1 which was designed to operate an UGV in a HFSE and perform maneuver, search, detect, and locate tasks (Nagle et al., 2008). The Use Case was built around locating a possible

enemy IED or firing point. This is a scenario that could be performed by autonomous, semi-autonomous or tele-operated UGV using current and future vehicle platforms.

Table 1. Use Case for locating a possible enemy improvised firing point/device.
(From Nagle, et al., 2008)

Use Case #1: Locate possible enemy improvised firing point/device	
Name Description	Maneuver, search, detect, and locate possible enemy improvised firing point/device.
Situation	Possible enemy improvised firing point/device. Iraq urban terrain; heavy civilian foot and vehicle traffic; enemy direct fire unlikely; daylight hours.
Task	Conduct reconnaissance using UGV.
Purpose	Confirm or deny possible rocket firing point.
Doctrine	ART 2.3 Conduct Intelligence, Surveillance, and Reconnaissance. ART 2.3.3 Conduct Tactical Reconnaissance MCT 2.2 Collect Data and Intelligence MCT 2.2.1 Conduct Tactical Reconnaissance
Notes	Maneuver operations are highly restricted since armored vehicles may damage streets, homes, automobiles, etc. Additionally, streets are often cluttered with day-to-day activities that should not be interrupted with military operations. There is much more background clutter in the form of radio transmissions, lights, pedestrians, civilian automobiles, and other interferences that degrade the performance of military communications, sensors, and human sensing. The probability of War fighter interacting with civilians is high so there is a much greater requirement for our War fighter to understand the local populace in terms of language and culture. Combat operations focus principally on a limited, concrete set of effects, such as the number of targets engaged.

4.3 Scenario Development

With Use Case #1 in mind and the maneuver, search, detect and locate threads, an IED scenario in a OneSAF urban environment was developed. The scenario situation, mission and execution are described in the following sections.

4.3.1. Situation

4.3.1.1 Enemy Forces

Insurgents have been targeting road intersections along Abu Ghrab Expressway (Rasid AlKaylani Street) with indirect fire (60-mm mortars). Intelligence confirms that the insurgents are operating from random locations within 1 km south of Rasid AlKaylani Street. IED are expected to be used defensively in the area surrounding the insurgent improvised firing positions. Three to six insurgents are believed to be in the area of operations (AO) and are equipped with 60-mm mortars and machine guns. Their most probable course of action (COA) upon detection will be to move individually to the south and hide among the buildings. One or more IED are suspected in the area surrounding the insurgent firing position.

4.3.1.2 Friendly Forces

Higher level Coalition headquarter's desire that the Abu Ghrab Expressway be secured, recently deployed UGV should be utilized in platoon level patrols, to secure the Expressway. These patrols will have two AH-64A-11 Apaches on standby for air support, and UGV teams will be attached.

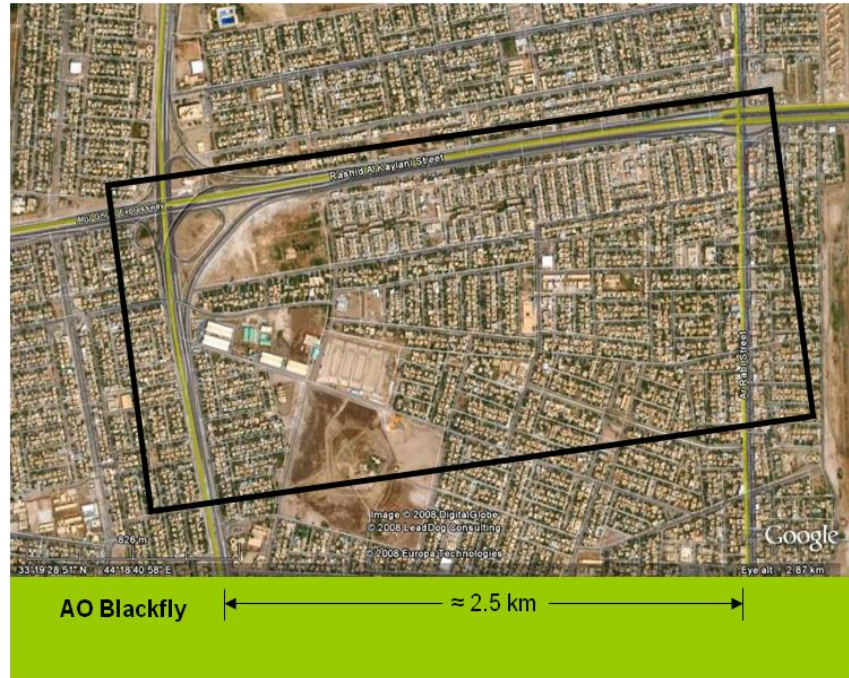


Figure 4. Area of Operations for the Use Case Scenario.

4.3.2. Mission

1st Coalition Stryker Recon Platoon with attached UGV team will conduct a reconnaissance of the AO BLACKFLY NLT TTTTDDMMYYYY to conduct route clearing operations along streets to the south of the Abu Ghrab Expressway. The platoon will move randomly along streets south of the Abu Ghrab Expressway. Upon discovery of an IED the area is to be cordoned off and air support called in.

4.3.3. Execution

The purpose of this mission is to neutralize the insurgents operating to the south of Abu Ghrab Expressway between intersections at approximately 33°19'40''N, 44°18'2''E and 33°19'48''N, 44°19'29''E, the intersection with ArRabi Street. These insurgents have been targeting the Expressway with indirect fire and IED. At the end of

this mission, we would like to have all IED threats and insurgents eliminated without the effects of collateral damage within the urban environment. The 1st Platoon will conduct the route clearance operation with the assistance of an UGV. They will conduct these operations with air support to ensure the safe transit of friendly units. Conduct of the operation with UGV and Stryker platoon moves in a column south of the Abu Ghrab Expressway to the objective. Upon discovery of an IED and insurgent indirect fire positions, the platoon calls for air support. On order, two AH-64A-11 Apaches attack insurgent position along axis Blue Arrow. If an IED explodes, the insurgents should scatter. If the IED is detected, but not detonated, the UGV should report its location and continue. The Stryker platoon should move to positions which block insurgent escape routes and call for air support. Insurgents may then scatter when rotary wing aircraft (RWA) arrives. Insurgents are found by RWA or by the Stryker platoon.



Figure 5. Scheme of maneuver. Google Earth image of the BLACKFLY AO.

4.4 OneSAF Scenario Implementation

4.4.1. Terrain and Environment

The Southwest Asia (SWA) terrain database is used with the OneSAF default values as follows in Table 2:

Table 2. Environmental Conditions

Temperature	21° C
Humidity	35%
Sunrise	0200 GMT
Sunset	1800 GMT
Moonrise	1800 GMT
Moonsset	0200 GMT
Visibility	100 %
Cloud Cover	2 %
Wind Speed	7 knots\hr from the north

4.4.2. Units and Task Organization

OneSAF entities and units selected to represent the Coalition and Insurgent forces are shown in Table 3.

Table 3. OneSAF Entities and Units

Unit or Entity	Description	Initial Position	OneSAF Filename
Coalition Forces			
1 st Platoon Stryker Recon	Includes four Stryker vehicles, Light and Heavy sections, each Stryker includes	33.31505° N 44.33443° E	.../mr/SBCT_UNIT/PL T/PLT_Stryker_recon_ With_Dismounts_SBC

	individual combatant dismount team.		T_Inf_Bn_US.xml
UGV	Specified in ANVEL, but use a OneSAF HMMWV for scenario testing without ANVEL.	33.32257° N 44.31180° E	Movement controlled by ANVEL
AH-64A-11 Apaches	Consists of five AH-64A-11 aircraft, only two are assigned tasks.	33.26222° N 44.24556° E	../lr/UA_VN_UNIT/PLT/PLT_ATK_ACFT_AH64A_ATK_RECON_CO_RWA_US.xml
Insurgent Forces			
Insurgent Squad	Mortar Squad with 182-mm Mortar Team, and GAZ66 Truck. The truck is manually destroyed during the scenario definition.	33.22456° N 44.31028° E	../mr/COMBAT/INFANTRY/SQD/SQD_Guerrilla_Mortar_OPFOR.xml

4.4.3. OneSAF Tasks

Table 4 shows the OneSAF tasks, purposes, and order of execution within the scenario.

Table 4. OneSAF tasks.

Execution Sequence	Unit or Entity	Task Names	Purpose	Order of Execution
1	Insurgent: ASST GUNNER- IC3	a) Move Tactically b) Emplace Explosives c) Move Tactically	Move to location; emplace an IED (203-mm, HE-FRAG with a proximity fuse) at 33.322697° N, 44.31081° E. Return to origin.	Upon execution of OneSAF (start of run)

Execution Sequence	Unit or Entity	Task Names	Purpose	Order of Execution
2	Insurgent: MTR TM LDR-IC1	a) Move Tactically b) Emplace Explosives c) Move Tactically	Move to location; emplace an IED (105-mm, HE M760 round using a trip wire) at 33.32273° N, 44.31075° E. Return to origin.	After (1) is completed.
3	Coalition: Stryker Platoon	After IC mount, follow route to final leg (Figure 5).	Simulates 4-km patrol through an urban area, prior to use of UGV for local reconnaissance.	After (1) is initiated.
4	HMMWV ¹	Tactical Move.	Lead patrol through urban area, then follow last leg into area of IED.	Prior to (3).
¹ Used only for testing scenario execution without ANVEL.				

4.4.4. OneSAF/ANVEL Scenario Execution and Lessons Learned

In order for the OneSAF scenario to execute as envisioned and be used as an analytical tool and reduce the amount of human intervention, a number of new or modified OneSAF behavior tasks and capabilities need to be developed. Note that these observations are based on OneSAF v2.1 and some of these maybe overcome by user developed behaviors using the OneSAF behavior development tool, and future OneSAF releases.

- Ground vehicle movement in urban terrain along streets is a known OneSAF problem; route planning near buildings, and sharp turns are difficult, and which need to be improved before this scenario can be used in a fully automated manner.

- Movement of the Stryker unit into and out of defensive positions/formation in the scenario (while waiting for UGV to conduct recon) was not possible due to urban route planning issues already mentioned above.
- Communication/situational analysis between entities in the same OneSAF unit works well, but allowing reports from another unit did not seem possible, nor is it yet possible to obtain reports from vehicles represented in ANVEL using MATREX. Although the issue of SALUTE reports and HLA has been discussed in the OneSAF user Forum.
- IED which can be created in OneSAF did not cause damage to the activating entity (this problem was reported to the OneSAF help desk).
- While convoys can detect area minefields and react, there currently is no behavior which allows units to detect IED and report or react to them.

Chapter 5: Assessing the UGV Testbed Engineering-Level Experiment

5.1 Measures of Effectiveness

In order to assess, quantify and communicate how well the testbed environment performs, several measures of effectiveness (MOE) are considered in the following areas: integration and interfaces to other models, run-time performance, fidelity, resolution, incorporation of human-in-the-loop (HITL) operation, graphics\scene quality, mission design to include the mission tasks and end-to-end test coverage, and the ease of development. Each of these will be detailed in this chapter.

5.1.1. Interfaces and Integration with Other Models

The testbed consists of ANVEL and OneSAF and integrates over the MATREX run-time interface (RTI) which facilitates the integration of multi-fidelity models and HITL interactions in an HLA environment as recommend in Goerger et al. (2008). Using this architecture will also allow the models within the testbed to potentially interface more easily to other models. Future experiments will look at incorporating higher fidelity sensor models from Night Vision Laboratory Toolkit and battle command and control from the Battle Command Management System. A MOE associated with this is the actual integration test coverage. This measures the fraction of the system that has undergone end-to-end testing satisfactorily. Another MOE considered is the complexity of interfaces and integration. The testbed environment needs to be capable of being replicated with the expected amount of effort. Component interface and middleware or integration code complexity should not be above and beyond what is currently expected given similar integration efforts done, i.e., BLCSE federation integration. Finally, the testbed should have adaptability thus allowing for the integrated system's ability to adapt to requirement changes.

5.1.2. Runtime Performance

The runtime performance of the testbed is near-real-time. The capabilities that exist within the testbed now as well as functionality that will be added in the future and continue to allow the testbed to perform at near-real time runtime performance are summarized below in Table 5. Runtime performance capabilities timeline.

Table 5. Runtime performance capabilities timeline.

Now	Near-Term <1 yr	Mid-Term 1- 2 yrs	Long-Term 3 - 5 yrs
UGV mobility	Improved collision detection	Improved mobility	High Fidelity IIR Sensors and Cameras
Optical Visual Cameras	Use of OneSAF sensors	Additional sensor models	HPC Environment (Not HLA Compliant)
SAF Environment	Leverage OneSAF capabilities	Integrate additional models	UGV functionality incorporated into OneSAF
HITL\UGV Interaction	Add C2/SA models	Semi-autonomous	Autonomous UGV

5.1.3. Fidelity

The capabilities that exist within the testbed now, as well as functionality that will be added in the future, are summarized below in Table 6. Fidelity capabilities timeline.

Table 6. Fidelity capabilities timeline.

Now	Near-Term <1 yr	Mid-Term 1- 2 yrs	Long-Term 3 - 5 yrs
HITL guided Mobility and Recon	Enhanced Collision Detection\Assisted Tele-OP	Waypoint navigation with operator inputs	Soil deformation
HITL Search and Optical Visual Cameras	OneSAF sensor capabilities (IR)	added sensor capabilities Semi-autonomous	Autonomous Search HPC High Res Environment (Not HLA Compliant)
HITL Detect	Integration of BCMS\NVL tools	Semi-autonomous Communication System Reporting	Autonomous Detection
HITL Locate	Improved C2/SA	Communication System Reporting	
Interaction with objects within ANVEL	One way interaction ANVEL → OneSAF	Limited two way interaction ANVEL ↔ OneSAF	Two way interaction ANVEL ↔ OneSAF

5.1.4. Resolution

Resolution is the measure of how much the model looks like the real thing. The resolution of the ANVEL model can be seen in Figure 6. ANVEL is capable of displaying ultra high resolution LIDAR data. The LIDAR data currently being used is 1cm resolution. OneSAF is capable of displaying low-resolution polygons with 20- to 30-cm resolutions.

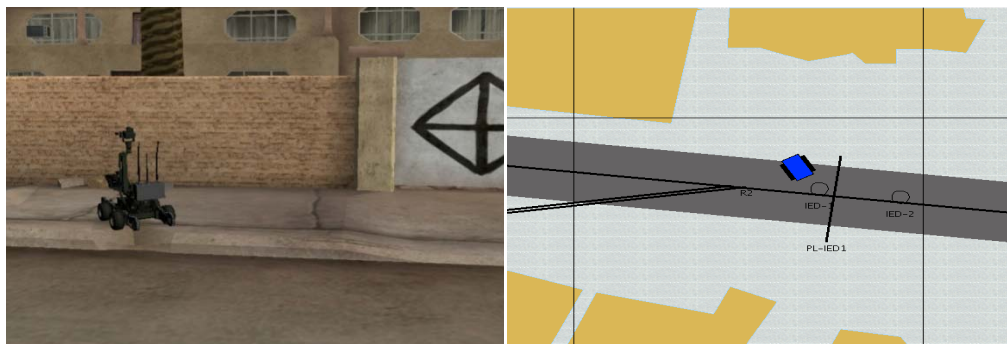


Figure 6. ANVEL (Left) and OneSAF (Right) testbed resolution.

OneSAF resolution is summarized as follows in Table 7. OneSAF Resolution (OneSAF Public Site, 2008):

Table 7. OneSAF Resolution

Low	Medium	High	Very High	Ultra High
1:1M	1:250K	1:50K	1:12K	Buildings

5.1.5. Incorporation of Human-in-the-Loop (HITL)

HITL tele-operation via keyboard or joystick operation moves the UGV within the ANVEL and integrated OneSAF model simultaneously. The HITL also facilitates message passing and situational awareness updates to the common operating picture (COP).

5.1.6. Graphics/Scene Quality

Figure 7 is a high quality picture comparable to high end gaming graphics.



Figure 7. ANVEL scene quality.

5.1.7. Mission Design

The UGV testbed should be able to accomplish the Universal Joint Task List (UJTL) (2008) and the Army Universal Task List (AUTL) (2003) tasks associated with UGV. The UJTL Tasks identified are summarized in **Table 8. Identified UJTL Tasks** below:

Table 8. Identified UJTL Tasks

OP 1	Conduct Operational Movement and Maneuver
OP 1.5.1	Control of operationally significant land area in the joint operations area
OP 2	Provide Operational ISR
OP 2.2	Collect and Share Operational Information
OP2.2.1	Collect Information on Operational Situation

OP 2.2.5	Collect Target Information
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The AUTL tasks identified are summarized in Table 9. Identified AUTL tasks below:

Table 9. Identified AUTL tasks

Art. 1.0	The Movement and Maneuver War fighting Function
Art. 1.2	Conduct Tactical Maneuver
Art 1.2.5	Exploit Terrain to Expedite Tactical Movements
Art 1.2.10	Navigate From One Point to Another
Art1.6	Conduct Mobility Operations
Art. 1.6.1	Overcome Barriers, Obstacle, and Mines
Art 1.6.2	Enhance Movement and Maneuver
Art 1.6.3	Negotiate a Tactical Area of Operations
Art 2.0	The Intelligence War fighting Function
Art 2.2	Support to Situational Understanding
Art. 2.2.3	Provide Intelligence Support to Protection
Art. 2.3	Conduct Intelligence, Surveillance, and Reconnaissance (ISR)

Art. 2.3.3	Conduct Tactical Reconnaissance
Art. 2.3.4	Conduct Surveillance
Art 2.4	Provide Intelligence Support to Targeting and Information Operations Capabilities
Art 2.4.1	Provide Intelligence Support to Targeting
Art. 2.4.2	Provide Intelligence Support to Information Operations Capabilities

5.1.8. End-to-End Test Coverage (Verification and Validation)

As the testbed environment grows to encompass additional models, the end-to-end test coverage will grow in complexity. It is desired that 100% end-to-end test coverage will be completed and it will be important to document the fraction of the systems functionality that has undergone end-to-end testing satisfactorily. This process is known as verification and validation of the testbed environment. As tests are completed it is especially important to complete the documentation of known limitations and work-arounds in order to inform about the actual functionality capable within the model. The actual thread tests conducted for Experiment 2 are discussed in great detail in section 5.3.

5.1.9. Ease of Development

It is important that the testbed that is developed is not so overly complex that it requires a highly skilled group of operators to recreate or use the environment. The development effort therefore concentrated on tools available to all stakeholders that do

not require an extended effort beyond what the stakeholders would need to operate this environment.

5.2 Design of Experiment

In conducting an experiment of the actual testbed itself, factors to be considered while assessing the environment are the 1) Sensors\Cameras with regard to the optical resolution, black and white versus color, contrast, camera field-of-view (FOV), and 2) the load on the federation such as the number of HITL\Workstations federated. These factors may have an effect on the measures of effectiveness as outlined in Section 5.1.

5.3 Verification and Validation

The verification and validation (V&V) of the federation is the most important part of assessing the UGV testbed. Verification is the process of determining if the modeling and simulation (M&S) represents the conceptual description of the UGV testbed. Validation is the process of determining to what extent the M&S adequately represents the real world functionality of the UGV in its real environment. The V&V is accomplished by identifying the mission threads that need to be assessed and then following these mission threads through all affected M&S. The mission threads for Use Case #1 were identified as the maneuver, search, detect, and locate threads. The operational and technical views of these threads were developed and are discussed in the following two sections. The operational perspective is the actual practical application within the testbed environment while the technical perspective is the M&S application within the testbed environment.

5.3.1. Maneuver Thread

The maneuver thread examines the UGV maneuver in ANVEL as well as in OneSAF. The UGV should move over the same route in each model and should correlate to the same terrain location in each model at every instance. As the UGV platform is maneuvered by the HITL operator, the information on the UGV entities location should update in real time in OneSAF. The location of the entity on the terrain should correlate with the location and terrain in ANVEL. Figure 8 and Figure 9 show the maneuver thread operational and technical perspective, respectively. The operational perspective of maneuver is described as follows. The route is planned for the entities to execute. The entities then traverse the terrain maneuvering the terrain and obstacles it encounters them. As the UGV encounters obstacles and reacts the UGVs location information is transferred to the other entities within the scenario.

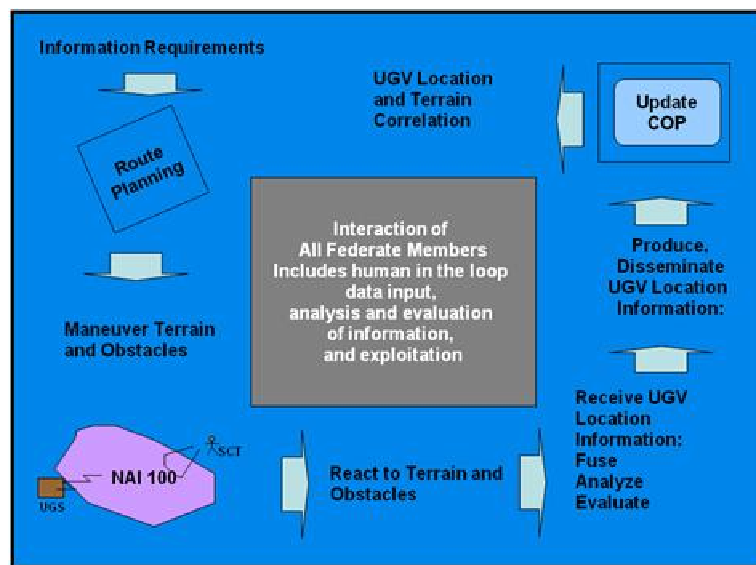


Figure 8. Maneuver thread operational perspective.

The technical perspective of maneuver is described as follows. The HITL controls and executes the UGVs maneuver as per the planned route by maneuvering the UGV within ANVEL. ANVEL displays the UGV in the high resolution environment and passes the UGVs current location information across the MATREX RTI to update the OneSAF COP of the UGVs actual location within the terrain.

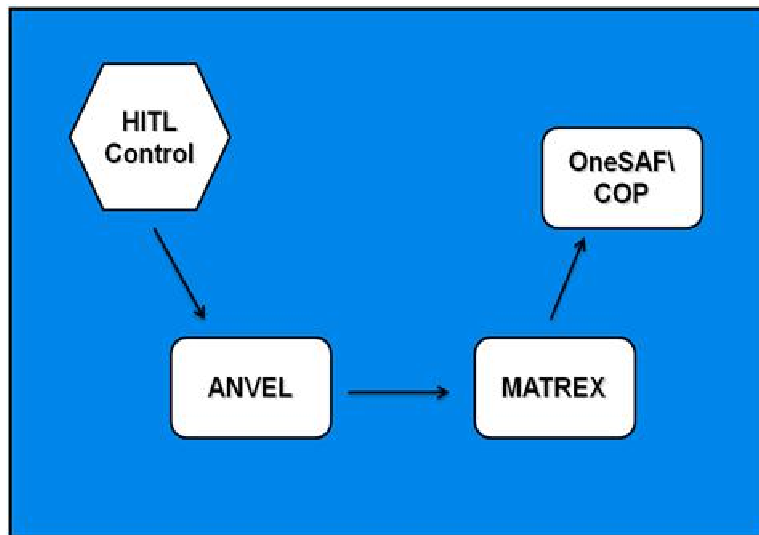


Figure 9. Maneuver thread technical perspective.

5.3.2. Search Thread

The search thread examines sensor\camera search functions within the testbed environment. Figure 10 and Figure 11 show the search thread operational and technical perspective, respectively. The operational perspective of search is as follows. Given the planned route, as the UGV moves along the planned route, the HITL moves the cameras within ANVEL to search the terrain.

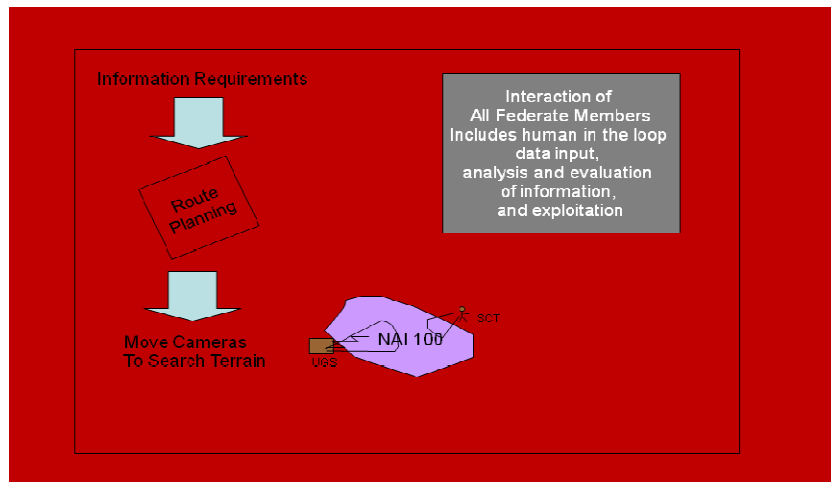


Figure 10. Search thread operational perspective.

The technical perspective for search is described as follows. The HITL controls the UGVs movement within ANVEL along the planned route as well as the movement of the cameras to search the environment.

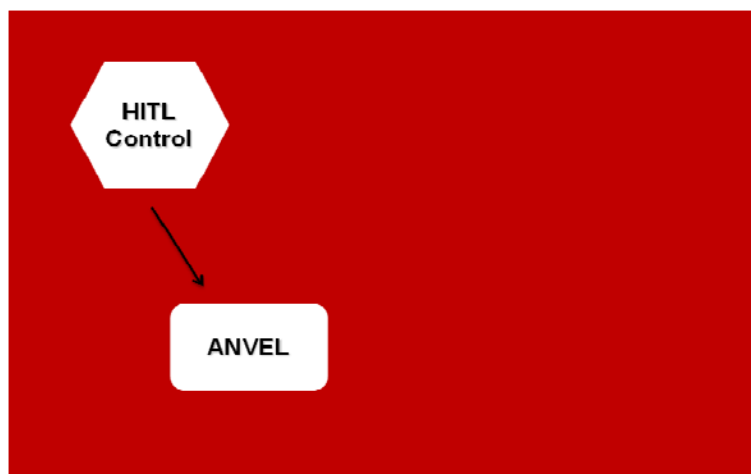


Figure 11. Search thread technical perspective.

5.3.3. Detect Thread

The detect thread examines sensor\camera detect functions within the testbed environment. Figure 12 and Figure 13 show the detect thread operational and technical perspective, respectively. The operational perspective is described as follows. The deployed camera allows the HITL to view objects along the planned route and the HITL uses judgment to determine if an object that is detected is an IED and should be reported higher.

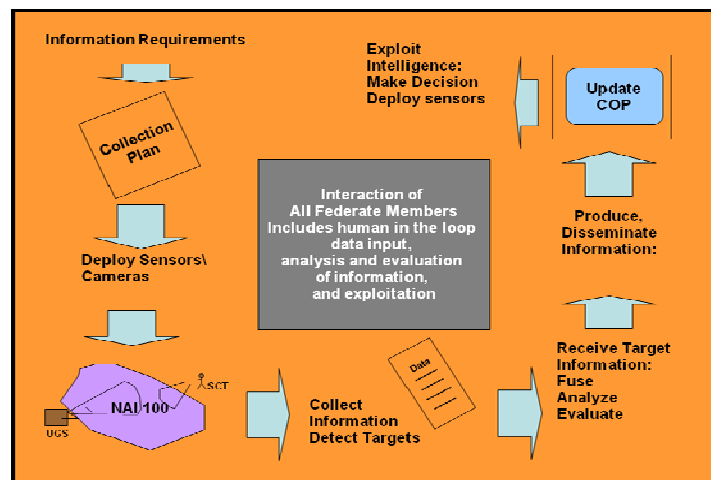


Figure 12. Detect thread operational perspective.

The technical perspective is described as follows. The HITL through viewing the camera view within ANVEL determines if an object is suspicious and warrants reporting to the COP. The HITL reports to the HITL controlling the COP to inform the entities within OneSAF that the IED has been detected.

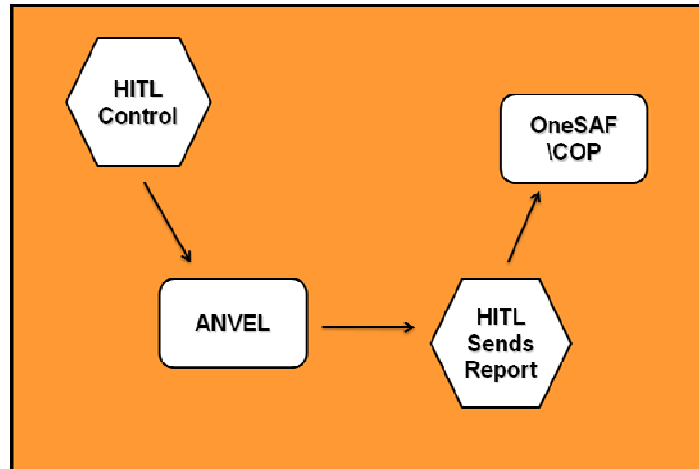


Figure 13. Detect thread technical perspective.

5.3.4. Locate Thread

The locate thread examines sensor\camera search functions within the testbed environment. Figure 10, Figure 14, and Figure 15 show the locate thread operational and technical perspective, respectively. The operational perspective is described as follows. Once the object has been detected to be an IED, the HITL determines the objects grid coordinates and the HITL reports the grid location to the HITL operator controlling the COP.

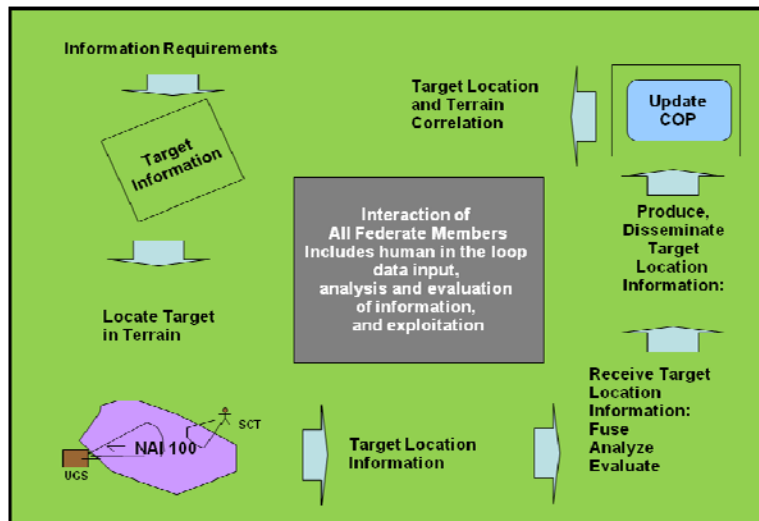


Figure 14. Locate thread operational perspective.

The technical perspective is described as follows. The HITL determines the grid coordinate location of the IED and reports the information to the HITL operating the COP. The HITL operating the COP then directs the OneSAF entities to react to the IED at the given location.

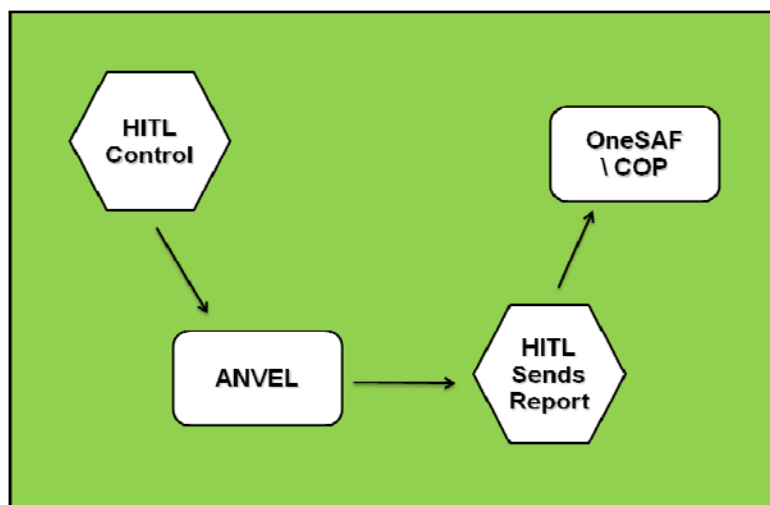


Figure 15. Locate thread technical perspective.

5.4 UGV Testbed Environment Experimental Results

The testbed has shown that ANVEL can interface and is integrated with OneSAF through MATREX. Given the role of MATREX within this federation, additional models should be able to fully interface and be integrated into the federation as additional M&S functionality is required.

The ANVEL\OneSAF\MATREX federation runtime performs at near-real time. Section 5.1.2 details additional functionality and when near-real-time runtime performance can be expected.

The modeling fidelity within the testbed relies heavily on HITL interactions especially with respect to situational awareness. Section 5.1.3 details the current fidelity of the M&S as well as projects future fidelity capabilities.

This testbed is a multiple resolution environment with ANVEL modeling the high resolution UGV environment down to 1-cm resolution.

This UGV testbed incorporates HITL and relies on the HITL to perform situational awareness and command and control functionality. Section 5.1.3 projects when semi- and autonomous functionality can be anticipated.

The graphics\scene quality is comparable to graphics within the gaming industry without sacrificing the physics-based modeling.

The mission design within the UGV testbed is capable of performing AUTL and UJTL tasks. The tasks for Experiment 2 are those associated with Use Case #1 already

detailed in Chapter 4 and employ the threads of maneuver, search, detect, and locate. The UJTL tasks are described in Table 8 and the AUTL tasks are described in Table 9.

One hundred percent end-to-end test coverage was completed on the UGV testbed environment. The V&V of the maneuver, search, detect, and locate threads conducted on the UGV testbed resulted in the following federation known limitations of no autonomous message passing (search\detect\locate). The work-arounds established to combat this limitation is to utilize HITL message passing.

Making use of OneSAF and the MATREX environment greatly assists in the ease of development of this federation testbed. The MATREX RTI and OneSAF are currently used in the BLCSE and, therefore, already have a base support of users and technical experience.

Chapter 6: Assessing the UGV Testbed Operational-Level Experiment

6.1 FCS UGV Performance Metrics

In assessing the actual UGV performance, the following FCS UGV performance metrics were noted. These performance metrics are where we chose the UGV performance metrics for assessing the UGV in the testbed with Use Case #1. The FCS UGV performance metrics are summarized in Table 10. FCS UGV performance metrics below:

Table 10. FCS UGV performance metrics

Primary	Secondary
Endurance	Air Drop-ability
Mobility	Robustness to Crashes
Payload Fraction	Reliability
	Signature
	Cost

6.2 Use Case #1 Measures of Effectiveness

Considering the FCS performance metrics, we determined the Use Case #1 measures of effectiveness (MOE). We selected the following MOEs as outlines in Table 11. Experiment 2 MOE's to focus on for Experiment 2:

Table 11. Experiment 2 MOE's

Endurance	Time
Mobility	
Urban	Speed
Rough	Speed
Open	Speed
Reliability	Probability of failure free system over specified period of time
	Exposure to threat
	% of Time Lost Communications

6.3 Design of Experiment

In conducting an experiment of the UGV within the testbed, factors to be considered while assessing the UGV measures of effectiveness are the 1) Terrain Type, 2) UGV Speed, 3) Time to mission accomplishment, and 4) Type of Platform, 5) Sensors\Cameras with regard to the optical resolution, black and white versus color, contrast, and camera FOV. These factors could have an effect on the measures of effectiveness as outlined in Table 11. Experiment 2 MOE's above.

Chapter 7: Summary

High fidelity environments are needed to impact UGV performance in synthetic environments (e.g., navigation, sensing, and movement). Based on stakeholder input, we have developed a UGV HFSE testbed for evaluating UGV design alternatives. The OneSAF\ANVEL Federation integrated with MATREX is conducive as a HFSE for UGV testing and analysis and has great potential for use within other federations.

Chapter 8: Future Work

FY09 work will integrate ANVEL with battle command tools while exploring other use cases as outlined in Nagle et al.,(2008). The addition of Command, Control and Communications (C3) Situational Awareness models will be explored so there is less reliance on the HITL to provide all SA on the UGV actions. This work may be extended to conduct virtual testing of red team robotics in the UGV testbed, to examine unmanned aerial systems (UAS) interoperability within this environment, to conduct UGV component optimization as well as to add additional UGV functionality\components into the UGV testbed.

The priority of work for future M&S enhancements to ANVEL are collision detection, damage assessment, autonomous controller and C3\SA work to facilitate two way communications between the models.

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Appendix A: Acronyms

A	
ACM	Association for Computing Machinery
AH	Attack Helicopter
ANS	Autonomous Navigation System
ANVEL	Autonomous Navigation Virtual Environment Laboratory
AO	Area of Operation
AT\AP	Antitank\Antipersonnel
ART	Army Tactical Tasks
AUTL	Army Universal Task List
B	
BFA	Battlefield Functional Area
BLCSE	Battle Lab Collaborative Simulation Environment
BLOS	Beyond Line of Sight
C	
C3	Command, Control, Communication
C4I	Command, Control, Communication, Computers, Intelligence
CBRN	Chemical, Biological, Radiological, and Nuclear
CBRNE	Chemical, Biological, Radiological, Nuclear, and High-Yield Explosive
CG	Commanding General
CGF	Computer Generated Forces
COA	Course of Action
COP	Common Operating Picture

D	
DIS	Distributed Interactive Simulation
DoD	Department of Defense
E	
ERDC	U.S. Army Engineer Research and Development Center
ERDC -CRREL	Engineer Research and Development Center – Cold Regions Research Lab
ERDC-GSL	Engineer Research and Development Center – Geotechnical and Structures Laboratory
F	
FCS	Future Combat Systems
FOC	Force Operating Capabilities
FOV	Field of View
G	
GMT	Greenwich Mean Time
GRMP	Ground Robotics Master Plan
H	
HFSE	High-Fidelity Synthetic Environment
HITL	Human in the Loop
HLA	High Level Architecture
HMMWV	High Mobility Multipurpose Wheeled Vehicle
I	
IEEE	Institute of Electrical and Electronics Engineers
IED	Improvised Explosive Device
IR	Infrared

ISR	Intelligence, Surveillance and Reconnaissance
J	
JAUS	Joint Architecture for Unmanned Systems
JGRE	Joint Ground Robotics Enterprise
L	
LIDAR	Light Detection and Ranging
LOS	Line of Sight
M	
M&S	Modeling and Simulation
MANSCEN	Maneuver Support Center
MARCORSYSCOM	Marine Corps Systems Command
MATREX	Modeling Architecture for Technology, Research and Experimentation
MCT	Marine Corps Tasks
MCTL	Marine Corps Task List
MEDEVAC	Medical Evacuation
MEVA	Mission Essential Vulnerable Area
MOE	Measure of Effectiveness
MOUT	Military Operations in Urban Terrain
N	
NLOS	Non-line of Sight
NLT	No later than
O	
OneSAF	One Semi-Automated Forces
ORCEN	Operations Research Center of Excellence

OSD	Office of the Secretary of Defense
P	
PEO-GCS	U.S. Army Program Executive Office Ground Command Systems
R	
RDECOM	Research, Development, and Engineering Command
RDT&E	Research, Development, Test and Evaluation
RS JPO	Robotic Systems Joint Project Office
RTI	Runtime Interface
RWA	Rotary Wing Aircraft
S	
S&T	Science and Technology
SA	Situational Awareness
SALUTE	Size, Activities, Location, unit identification, Time and Date, Equipment
SBCT	Stryker Brigade Combat Team
SDP	Systems Decision Process
SQD	Squad
SWA	Southwest Asia
T	
TENA	Test and Training Enabling Architecture
TRADOC	U.S. Army Training and Doctrine Command
U	
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle

UGV	Unmanned Ground Vehicle
UJTL	Universal Joint Task List
UMS	Unmanned Systems
UNTL	Universal Naval Task List
USMA	United States Military Academy
V	
V&V	Verification and Validation
VANE	Virtual Autonomous Navigation Environment

Appendix B: Stakeholder Analysis Recommendations

Findings	Conclusions	Recommendations
Desire for HFSE to readily integrate through interfaces with other models, simulations, and systems.	Use existing policies, directives, and best practices that address standards and open architectures to minimize re-engineering.	HFSE should conform to data, data interchange, information exchange and communications standards including JAUS.
Requirement (2013) for a Common Open Architecture.	Desire to incorporate simulated and real systems such as control units.	HFSE should have HLA or DIS compliant external interfaces.
JGRE mandates JAUS for all its programs.	Desire for human-in-the-loop interactive mode as well as other modes.	Investigate Common Open Architecture requirement and its impact on HFSE users.
Need for near-real time or faster computational performance.	Desire to run simulations in near-real time or faster.	Must have near real-time for certain applications and determine areas where feasible in near-, mid-, and long-term.
Higher fidelity terrain and models will add value to modeling UGV systems and subsystems performance.	Level of fidelity and resolution needed for terrain/environment and models dependent on study issues and components.	HFSE should have multi-resolution capabilities.
Need for dynamic terrain, weather, and obscurant representation.	Desire dynamic terrain.	
Want 3D visualization for humans-in-the-loop simulation to look very realistic.	Desire realistic scene generation or image rendering.	HFSE must include 3D visualization for multiple display units.
Modeling communications between UGV platforms (current and future) and controllers or other systems is important.	Incorporate terrain features and attributes so as to impact LOS/NLOS/BLOS communications.	Investigate communication algorithms used by different programs and determine impacts on environmental content and representation.
The most frequently cited gaps identified in the GRMP were associated with maneuver, search, detect, and locate tasks.		

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14. ABSTRACT Geospatially enriched synthetic environments are needed for development and assessment of unmanned ground vehicle (UGV) performance to support sensor fusion and sense making. This work will address how the high-fidelity environment is achieved and integrated to inform simulations addressing critical questions. We will investigate a multi-resolution modeling capability to inform development of a high-fidelity synthetic environment (HFSE) testbed and to link to other models and simulations. This report will discuss results and lessons learned in developing an engineering- and operational-level experiment for proof of concept.					
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