THE 3RD INTERNATIONAL DEFENSE AND HOMELAND SECURITY SIMULATION WORKSHOP

SEPTEMBER 25-27 2013

ATHENS, GREECE

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PRINTED IN RENDE (CS), ITALY, SEPTEMBER 2013

ISBN 978-88-97999-15-7 (paperback)

ISBN 978-88-97999-21-8 (PDF)

ISBN 978-88-97999-15-7 (PAPERBACK)
ISBN 978-88-97999-21-8 (PDF)

THE 3RD INTERNATIONAL DEFENSE AND HOMELAND SECURITY SIMULATION WORKSHOP, DHSS 2013

SEPTEMBER 25-27 2013 - ATHENS, GREECE

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WELCOME TO DHSS 2013!

We extend our most sincere welcome to all attendees of this year's 2013 International Defense and Homeland Security Simulation Workshop being held in beautiful Athens, Greece.

Simulation in Defense and Homeland Security is becoming more important and pervasive due to opportunity to use Modeling & Simulation (M&S) approaches combined with new technologies (i.e. mobile technologies) across the whole spectrum of military operations. Indeed while training and decision support are the traditional application areas for M&S in the Defense and Homeland Security domains, new opportunities arise in which M&S can be profitably used to validate innovative concepts: design and acquisition of new systems and technologies, interaction between human and autonomous systems, advanced human behavior modeling, systems and networks integrations to cite a few.

As in the past, the DHSS workshop has included a diversity of topics presented by authors from many different institutions. This brings a plurality of interests and perspectives to a single location. Making the event even more compelling is the partnership within I3M (The International Multidisciplinary Modeling and Simulation Multiconference) which allows for even more cross pollination (this year I3M includes 7 international conferences/workshops). We hope you take advantage of this opportunity and contribute, through presentations, discussion and interaction, to the development of new ideas and new directions in research and applied technology. In addition to the many technical sessions, there is always the opportunity to share ideas and discuss approaches during the breaks and on the sidelines.

We hope you find the DHSS Workshop and the I3M multi-conference, including the keynote speakers, the technical sessions and other program events educational and interesting. Our thanks go out to all the authors, to the papers reviewers and the keynote speakers who have helped to make this year's Workshop a success.

We wish you a very successful workshop and we hope you will enjoy Greece, the birthplace of Democracy and Philosophy, as well as Athens, one of the oldest city in the world with more than 3000 years of history.

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ACKNOWLEDGEMENTS

The DHSS 2013 International Program Committee (IPC) has selected the papers for the Conference among many submissions; therefore, based on this effort, a very successful event is expected. The DHSS 2013 IPC would like to thank all the authors as well as the reviewers for their invaluable work.
A special thank goes to all the organizations, institutions and societies that have supported and technically sponsored the event.

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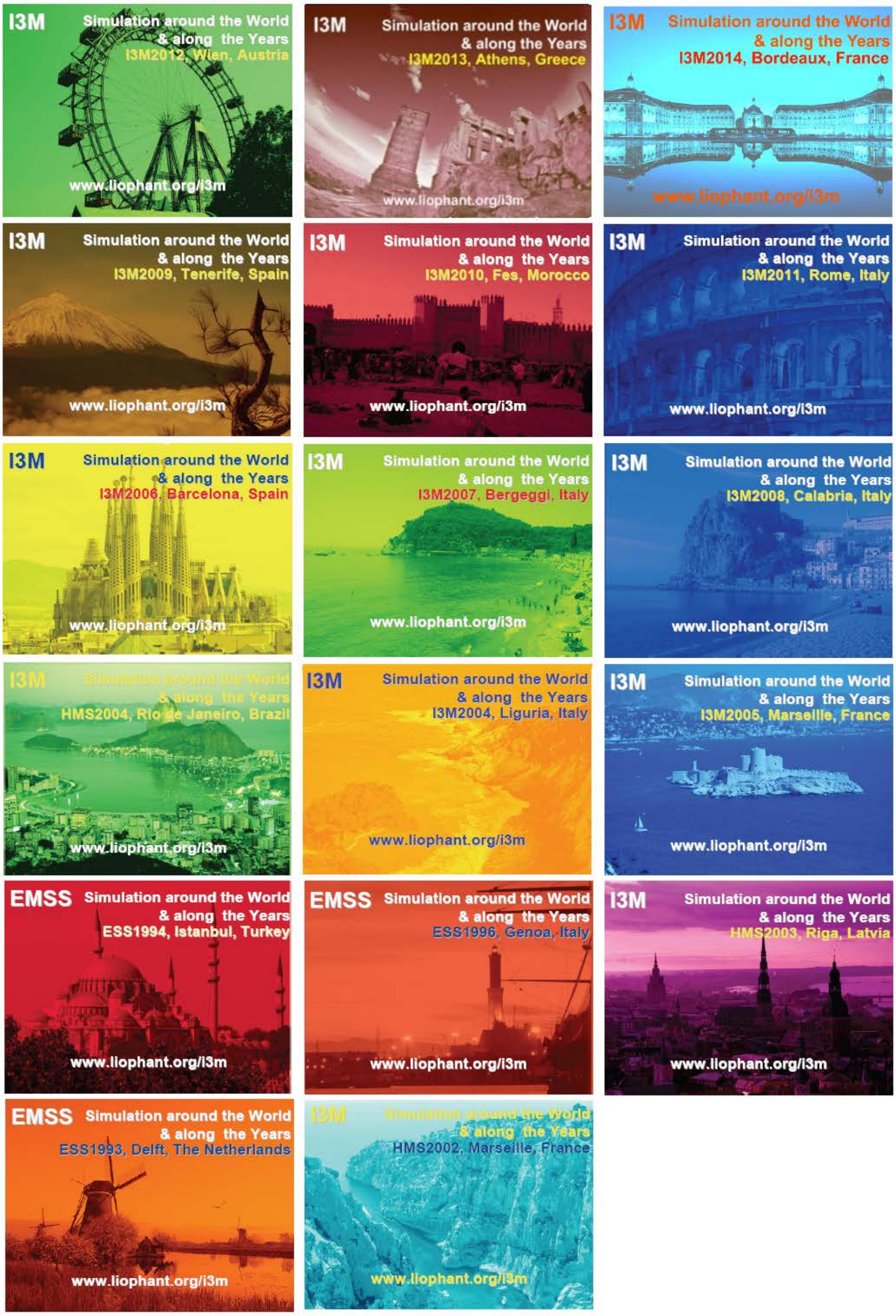

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SYNTHETIC BATTLEFIELD BASED SIMULATION FRAMEWORK FOR THE AVIATION ENGAGEMENT IN DISTRIBUDTED SYSTEM

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ABSTRACT
This paper presents a framework for the synthetic battlefield based aviation engagement simulation in the distributed system. The framework represents the radar detection system based on the synthetic battlefield using HLA (High-Level Architecture) based distributed system. An engagement simulation system requires the synthetic battlefield to reflect environmental effects to the simulation result, because behaviors of weapon systems are vulnerable by environmental effects in the real engagement. However, it is difficult to apply environmental effects to the engagement simulation by a gap between the requirements of simulation engineers and the provided data by environment engineers. This paper proposes a framework to bridge the gap and applies the framework to the synthetic battlefield for the radar detection system. This paper demonstrates the proposed framework by the implementation of the aviation engagement simulation in HLA system as an example, and the simulation results are changeable by environmental effects on the detection system.

Keywords: Aviation Engagement, Distributed System, High-Level Architecture (HLA), Radar Detection System, Synthetic Battlefield

1. INTRODUCTION

Due to the future combat paradigms that have been changed along the remarkable progression of the weapon system development, military forces are facing unprecedented, various, and complex requirements for such as the tactical deployment and new weapon development. However, available military resources are limited comparing to the requirements. Defense Modeling and Simulation (DM&S) has risen as a key to solve the conflict between the resource and the requirements. DM&S helps the efficient resource consuming plans by the verification of whether a plan meets the requirements, before the resources were committed. Thus, DM&S is an inevitable trend for whom to operate military forces (Smith, 1998). Recently, many countries endeavor to apply DM&S, beyond the traditional purposes such as the training and analyzing, to the acquisition cycle of weapon systems that comprises seven steps; development concept, design verification, prototyping, evaluation and testing, production and deployment, operation, and subsequent logistics (Keane et al., 2000).

DM&S is classified by the detail level of the representation defined by the DoD (Department of Defense) into four levels: campaign, mission, engagement, and engineering. The engagement simulation model, which is the target level of this paper, describes sophisticated behaviors and functions of weapon systems for short duration from minutes to hours, but it is not concerned with tactical command relatively. The expected outcomes of the engagement simulation model are such as survivability, vulnerability, and detection-ability of weapon systems (Hawley and Blauwkamp, 2010). According to the characteristics of the engagement simulation model, the model has to represent design properties and behaviors of each weapon system that is involved in the combat. However, the operation results of weapon systems are possible to not-follow own design factors in the real engagement situations, because of environmental effects. The environmental effects can be a decisive factor to decide the success of operations by referring to the history of war, and it is still effective, although the technologies of the weapon systems have been very developed (ROKSA, 2007). Hence, the engagement simulation model requires the synthetic battlefield to reflect environmental effects to the simulation entities, and the simulation results have to be changeable by the effects from the synthetic battlefield (Park et al., 2010).

In spite of the importance of embedding the synthetic battlefield in the engagement simulation, the construction of the synthetic battlefield has been hindered by the gap that is the synthetic battlefield for engagement simulations, simulation engineers (whom that construct a simulation system) demand environmental data of which are formed to meet the simulation purpose. But environment engineers provide only sets of numerical environmental data collected from observation. The gap between the requirements and the available service causes difficulties for the construction of the synthetic battlefield. Thus, existing efforts on developments of the engagement simulation were not available to reflect environmental effects, because simulation engineers could not use the provided environmental data from environment engineers.

In order to bridge the gap, this paper proposes a framework to construct a simulation system in the distributed system using HLA (High-Level Architecture). HLA is the standard for the distributed system by IEEE 1516 (IEEE Std 1516^{TM}, 2010), and it is developed to facilitate the interoperability and reusability by M&SCO (Modeling and Simulation Coordination Office: an affiliated organization of US DoD to lead DoD M&S standardization and empowering M&S capabilities) (M&SCO, 2012). In HLA, an entire system is called as 'federation' and each client is called as 'federate', and other details of HLA will be described in the section 2. The approach is for the HLA based simulation system including an environment federate of which stores numerical environmental data and extracts the data to meet requirements of the engagement simulation. In this paper, the framework is applied to the radar detection system. Hence, the framework proposes a design of the system that reflects environmental data to the radar detection probability computation.

The main objective of this paper is to propose a framework for the aviation engagement simulation with the radar detection system based on the synthetic battlefield, in order to bridge the gap in the reflection of environmental data provided by environment engineers to the simulation. The results of the simulation are diverse by the radar detection probabilities which reflect environmental effects. This paper demonstrates the proposed framework by the implementation of an example system based on the proposed framework.

This paper is organized as follows. Section 2 explains the approach of this paper. Section 3 details the proposed framework for the aviation engagement simulation system, and section 4 includes a description of the implementation of an example system for the demonstration of the proposed framework. Finally, section 5 summarizes the main conclusion of this paper.

2. APPROACH

2.1. HLA based Distributed System

The HLA based distributed system is one of the indirect communication systems that follows P-S (Publish-Subscribe) paradigm and this is designated by a server and clients, for distributed event-based systems. In the system, clients are assumed as publishers and/or subscribers, publishers publish structured events to an event service and subscribers express interests on particular events through subscriptions (Coulouris et al., 2012).

In the simulation system that is based on HLA, a client is called as a federate, and federates publish/subscribe information to/from the RTI (Runtime Infra Structure) server. RTI is software that is an implementation of HLA. The whole simulation system is termed as federation. This specifies, in advance the start of a simulation, a set of federate applications and a common Federation Object Model (FOM). FOM is a specification that defines the information which is exchanged at runtime to achieve the given objectives of federation. It includes communication detail of federates, such as object/interaction classes which are ways of communication among federates.

In order to communicate with the RTI server, a federate is indispensable to have an interface. This is referred to as Simulation Object Model (SOM), and SOM contains information on what its federate is going to publish and/or subscribe data of the classes that are defined in FOM.

In HLA based distributed system, the application connects RTI server as a federate that environment federate subscribes synthetic battlefield information and publishes the pertinent environmental data. The battle simulator federate publishes the synthetic battlefield information and it subscribes environmental data of the requested battlefield which is published by the environment federate. It uses the subscribed data to increase or decrease the characteristics of battle objects that are affected by the environmental effects. According to the variation, the results of an engagement simulation are changeable (ADSO, 2004).

2.2. Synthetic Battlefield for Aviation Engagement

In the aviation engagement, radar (an abbreviation for RAdio Detecting And Ranging) is the most efficient detection system to search objects, such as aircraft, ships, and missiles, in a specific area. The radar detection system uses radio waves, and it is composed of two parts; a transmitter and a receiver. The transmitter emits pulses of radio waves, and the emitted radio waves propagate along the straight line of the emitted direction of the transmitter as light speed. The emitted radio waves are bounced from the objects that are in the way of the propagation direction, and the bounced radio waves are returned to the receiver. The radar detection system analyzes differences between the returned radio waves and the emitted radio waves to determine the object that the radio waves were bounced from.

During the travel of the radio waves from the transmitter to an object and from an object to the receiver, the radio waves are propagated in the atmosphere, such as the troposphere and the stratosphere. Although the propagation of radio waves is predictable by the mathematical equation in the free space, the atmosphere of the real battlefield for the engagement is not the free space. The atmosphere includes various elements that are not equal by times, days, regions, heights, and so on, such as water vapor in the troposphere, and those elements cause the phenomena of reflection, refraction, diffraction, absorption, polarization and scattering, which affect the propagation of the radio waves. By the effects of the phenomena to the radio waves, the attenuation of the radio waves is occurred. The radar detection system is able to confuse the determination of the returned radio waves, because the radio waves can be weaker than the detection threshold of the radar system or can be modulated to be difficult to identify.

Due to the relationship between the radio waves and the atmosphere, the probability that the radar

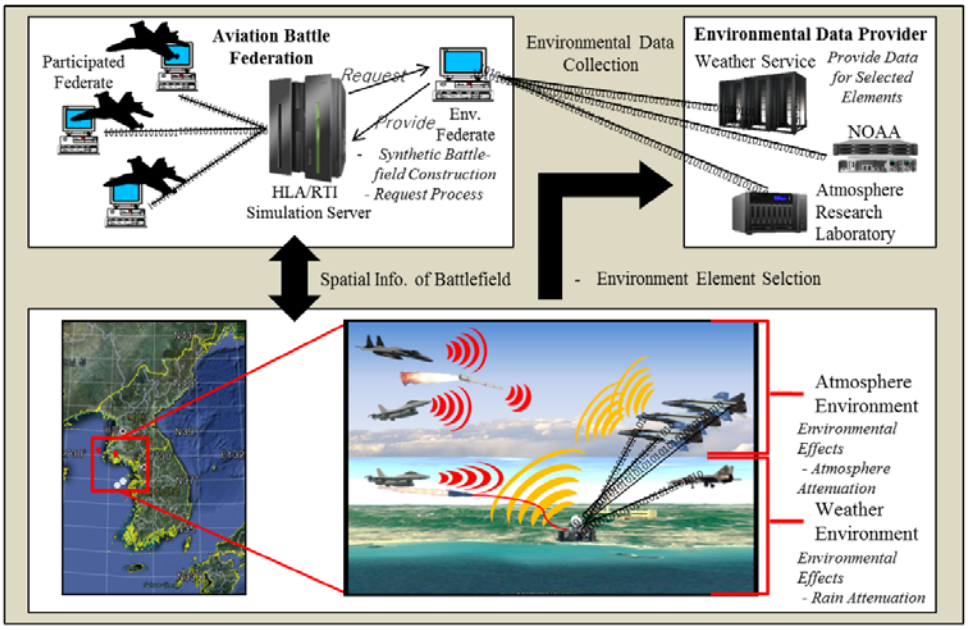

Figure 1: Synthetic Battlefield Construction for Aviation Engagement

detection system detects objects in the searching area is not constant as in the free space, but rather a value which is changeable by environmental effects. Therefore, the detection system in the aviation engagement simulation has to be based on the synthetic battlefield to reflect environmental effects to the computation of the detection probability.

By the former research, propagation of radio waves is attenuated by the rain and atmosphere elements. There are environmental elements that are decisive for the strength of two types of attenuation, such as precipitation for the rain attenuation and oxygen and vapor density in atmosphere for the atmosphere attenuation. Accordingly, the synthetic battlefield for the aviation engagement simulation is required to contain environmental data for the two types of attenuation and provide of the HLA based simulation system. For this process of the synthetic battlefield construction based on the environmental data, environment federate is laid in the engagement system to take the role shown as Figure 1.

3. SIMULATION FRAMEWORK

In the federation for the aviation engagement simulation, each federate connects to the federation as a function of the entire system, although a federate operation seems an independent application in a terminal that runs the federate. In this paper, the federation is structured as three federate; simulation federate, environment federate and radar detection federate (see Figure 2). The simulation federate has simulation entities, such as radar bases, aircraft, and missiles, and it executes the anti-air

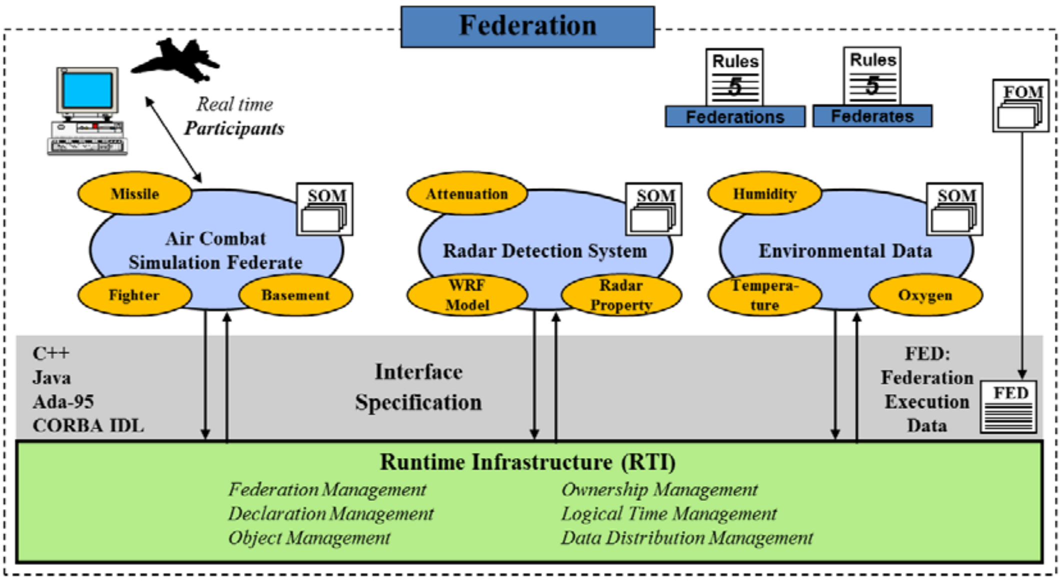

Figure 2: Federation Structure

Proceedings of the International Defense and Homeland Security Simulation Workshop 2013,
ISBN 978-88-97999-21-8; Bruzzone, Buck, Longo, Sokolowski and Sottilare Eds.

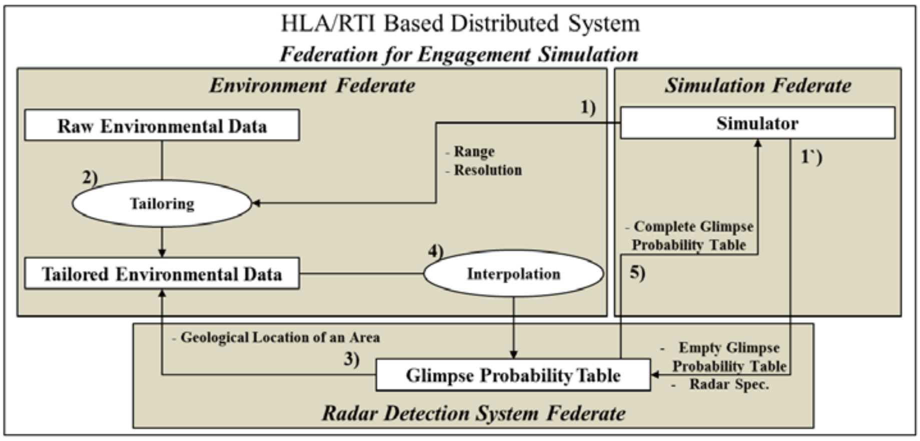

Figure 3: Data Interchange Procedure

engagement simulations using the simulation entities. The radar detection federate calculates radar detection probabilities using radar specification factors and environmental factors, and the environment federate searches environmental data of the synthetic battlefield. The operation results of each federate are exchanged via RTI server, and the data interchange procedure of the federation is described in Figure 3.

Before an explanation of the data interchange procedure, it needs to be represented that the concept of a table for interchange of detection probabilities. In this paper, we adopt 'GP (Glimpse Probability) table' to help reflection of radar detection probabilities among simulation entities. The GP means a detection probability at the indicated distance range, and a GP is computed using the radar performance and environmental data. The GP table defines detection probabilities by distances between a radar system and objects, so it is able to be applied to the detection states of simulation entities in the engagement. Using the GP table, detection probability P is calculated by formula (1), and accumulated probability F is calculated by formula (2). Thus, the detection probability of an enemy entity is increase along F (Driels, 2004).

$$P_n = (1\text{-}GP_1) \cdot \ldots \cdot (1\text{-}GP_{n\text{-}1}) \cdot GP_n \quad (1)$$

$$F_n = \sum_{k=1}^{n} P_k \quad (2)$$

In the proposed framework, all data interchanges are executed via RTI server by protocols of HLA based distributed system. A process of a publisher federate publishes a data and a subscriber federate subscribe the data is written as a term of 'Sending' in the explanation of the procedure. The data interchange procedure is explained as follow.

1) The simulation federate sends time and spatial information to the environment federate.
1`) The simulation federate sends radar location information, specification and empty GP table to the radar detection federate.

2) The environment federate extracts environmental data for the received information from the database.

3) The radar detection federate sends the received radar location information to the environment federate.

4) The environment federate sends environmental data for the received radar location information.

5) The radar detection federate completes the GP table using the internal propagation model and the environmental data from the environment federate and radar specification. The complete GP table is sent to the simulation federate.

Finally, the simulation federate applies the received complete GP table to detection states of simulation entities in the aviation engagement simulation. By the proposed framework, environment engineers are for the environment federate, radar engineers are for the radar detection federate and simulation engineers are for the simulation federate.

4. IMPLEMENTED RESULT

The proposed framework is implemented as an example system. The federates of the framework are developed using C++ programming language and MFC (Microsoft Foundation Class) library, and the federation is constructed on pRTI 1516® developed by Pitch. Atmosphere environmental data of the environment federate are collected by Korea meteorological administration. The simulation federate executes simulations using OGRE3D (Object- oriented Graphics Rendering Engine 3D) that is a C++ based open visualization engine library.

The example system executes simulations for the example scenario the following scenario. Enemy aircraft are generated in the aircraft generation zone 'A' and moving across the area, which is under surveillance by the ally surface ship, to reach the aircraft destination zone 'B' that is laid on the opposite side of the generation zone. If the surface ship detected enemies, it launches missiles to enemies, and the missiles trace enemies to shoot them down. The aircraft can be

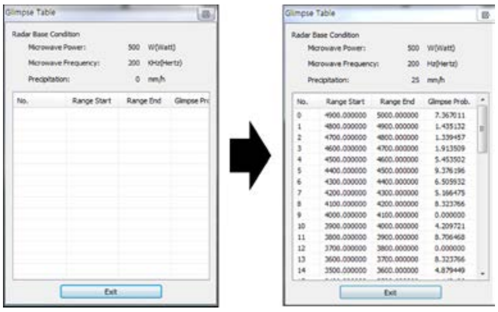

Figure 4: GP Table Generation

destroyed by missiles or can be survived and arrive at the destination. For the simulation of the example scenario, the surface ship calculates the distances between itself and every aircraft and derives the glimpse probabilities at each distance from the GP table. The surface ship launches missiles to enemies that are detected based on the GP. After launching a missile from the surface ship, the missile flies to the targeted enemy aircraft. A missile has maximum tracing distance and flight speed, and an aircraft also has the movement speed. If a missile navigated as much as the maximum tracing distance, the missile stops tracing the target and the targeted aircraft is able to arrive at the zone 'B'.

The implemented results of the example system are shown in next. Figure 4 is the representation of GP table generation. Figure 5 is the 3D visualized results of the example scenario simulation.

5. SUMMARY AND FUTURE STUDY

The proposed framework of this paper was developed to bridge the gap that is mentioned in the introduction, and the framework was applied to the anti-air engagement simulation for reflecting environmental effects of the atmosphere to the radar detection system in this study. In order to apply environmental effects of the atmosphere to the radar detection system, this paper defined the essential environmental factors which causes the attenuation to the propagation of radio waves. During the execution of the anti-air engagement simulation, the complete GP table is utilized to decide detection states of enemy aircraft by the simulation federate. Finally, the anti-air engagement simulation system based on the proposed framework of this paper performs simulations with the synthetic battlefield based radar detection states.

This paper is the radar base location is constant during the simulation. Thus, the creation of the GP table is occurred once at the beginning of the simulation. In the future study, the location of the radar base is changeable, and the GP table is re-created by the movement of the radar base.

ACKNOWLEDGMENTS

This work was supported by the Defense Acquisition Program Administration (DAPA), the Agency for Defense Development (ADD), and Korea Association of Industry Academy and Research Institute (C00035790100384919) under the Contract No. UD110006MD (DAPA), UD100009DD &

(a) Surface Ship

(b) Engagement

(c) Detected and Destroyed Aircraft

(d) Undetected and Survived Aircraft

Figure 5: Simulation Results

UD120035JD (ADD). The authors wish to express sincere gratitude for the financial support.

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SERIOUS GAME DEVELOPMENT METHODOLOGY VIA INTEROPERATION BETWEEN A CONSTRUCTIVE SIMULATOR AND A GAME APPLICATION USING HLA/RTI

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ABSTRACT
This paper proposes a serious game development methodology that utilizes interoperation between an existing virtual world application and constructive simulators. For time synchronization and data conversion between them, the proposed methodology is comprised of three specified processes: game loop analysis, game agent design and development, and parameter tuning. We use a High-Level Architecture (HLA) to ensure interoperation. By interoperating a constructive simulator with an existing virtual world application, a serious game developer can save effort by extending a serious game application, rather than building a serious game from scratch. In addition, trainees can obtain more realistic experiences.

Keywords: Interoperation, System of Systems, Constructive Simulator, Serious Game, Virtual Military Training

1. INTRODUCTION
With the impressive growth of the game industry over the last several decades, serious games have emerged to educate and train learners, rather than provide entertainment. Serious games allow learners to experience situations that are impossible in the real world due to safety, cost, and/or time. For this reason, the game industry has developed various types of serious games, including games for military, manufacturing, and medical purposes.

In the military field, several commercial serious games, such as Virtual Battle Space 2 (VBS2), Military Open Simulator Enterprise Strategy (MOSES), and Delta3D, are already available in the market. The main purpose of these games is to simulate military situations, and they fundamentally allow users to edit terrain and scenarios to create specific war environments. Nevertheless, a problem with these serious games is the limited accessibility granted to their operating systems; thus, these games only enable war scenarios and terrain within a limited scope (Gwenda, 2004). In addition, these games are based on game engines that lack modifiable script languages. Therefore, the creation of new war scenarios, modeling of combat entities, and reuse of such entities are greatly hindered, which results in a failure to adapt expandable war scenarios (Part et al., 2010). Such limitations restrict more detailed and expandable representations of military simulation development.

Our approach, therefore, overcomes the precedent limitations of utilizing existing military serious games for expandable war scenarios. To this end, we have paid attention to separating game applications from scenario interpreters. Game applications are existing military serious games, such as VBS2, MOSES, and Delta3D, whereas scenario interpreters are constructive simulators that generate dynamic situations based on the users' requests. Specifically, users generate war scenarios through a constructive simulator, and the simulator sends the scenario to the game application for battlefield visualization. While users conduct training through the scenario within the game application, mutual interactions frequently occur between the game application and the constructive simulator. Accordingly, the key issue for this approach is the method of interaction between these two separated parts.

The Federation Development and Execution Process (FEDEP) is a standardized process for developing interoperable systems. Because FEDEP is a general-purpose process that needs to describe two specific kinds of systems (the game application and the constructive simulator) and represent the characteristics of their interactions, we have customized the existing FEDEP and propose the new Military Serious Game Development and Execution Process (MSGDEP). The primary purpose of the MSGDEP is to provide not only a process, but also facilities that assist the existing game application in utilizing expandable war scenarios.

Thus, in this paper, we propose the MSGDEP for interoperation between game applications and constructive simulators. Specifically, the proposed methodology centers on two ideas: 1) time synchronization and 2) data conversion. To satisfy both ideas efficiently, the MSGDEP is comprised of three specified processes: game loop analysis, game agent design and development, and parameter tuning. To interoperate between the game application and the constructive simulations, we use a High-Level Architecture (HLA), which is used for distributed computer simulation systems. In our empirical study, we achieved time synchronization and data conversion based on the HLA (IEEE 1516-2010). By interoperating the constructive simulator with the existing virtual world application, serious game developers can save effort by extending a serious game application, rather than building a new serious game from scratch; in addition, trainees can acquire more realistic experience.

As a case study, we built and developed a military training scenario for a Nuclear/Bio-Chemical (NBC) situation. The outcomes of the case study will show the usefulness of the proposed work, such as how the flexibility and reconfiguration of the war game scenario improve, as well as how effectively the users can train within the scenario. The successful execution of this study can offer an immediate application for military training, and is particularly suited to war scenarios based in the Korean Peninsula.

The rest of the paper is organized as follows: Section 2 introduces existing military game applications and FEDEP. In Section 3, we explain the proposed SGDEP via interoperation between a game application and constructive simulators. Section 4 illustrates a case study that incorporates the proposed methodology, and finally, Section 5 concludes this study and proposes future extensions for a more complete solution.

2. RELATED WORKS

In this chapter, we will first introduce the existing serious games and describe FEDEP, which is a standardized and recommended process.

2.1. Virtual Battlespace 2 (VBS2)

The VBS2 is a comprehensive, open platform that uses gaming technology to provide tactical training experience and mission rehearsals (Virtual Battlespace 2, 2013). Several case studies have shown that VBS2 provided an immersive experience to a trainee through lifelike virtual environments. VBS2 provides two methods to extend its platform: integration and interoperation. First, VBS2 provides a plug-in interface for developers, so that other simulation systems can be coupled tightly with VBS2. Second, VBS2 allows for interoperation between various simulation systems via the DIS protocol or HLA. Therefore, in order to extend VBS2, the developer may choose between integration and interoperation. When using the integration method, the developer should understand the game loop of VBS2, so that the simulation system can be tightly integrated into VBS2. On the other hand, in order to extend VBS2 via interoperation, VBS2 participates in the federation and interoperates with other simulation systems. However, to the authors' knowledge, no methodology has been proposed to support interoperation between VBS2 and an existing constructive simulator. For our research, we modified the existing federation development methodology. By clarifying the requirements for each development phase, a developer can define the shared information between a serious game and a constructive simulator, and implement them easily.

2.2. Military Open Simulator Enterprise Strategy (MOSES)

The US Army Research Laboratory Simulation and Training Technology Center (ARL-STTC) developed a virtual world application called the Military Open Simulator Enterprise Strategy (MOSES) for military training needs (Maxwell et al., 2012). In order to develop a flexible virtual training framework, the ARL-STTC conducted research that utilized gaming and virtual world technology. To develop a flexible virtual training framework for trainers and trainees, the framework needed to allow for variable fidelity, based on the training objectives. MOSES is based on the Open Simulator, which is an open-source project to provide a virtual world server that can be accessed via the same viewer as SecondLife (OpenSimulator, 2013)

Similar to SecondLife, users of MOSES can upload and present content, such as buildings, objects, or training content, into the virtual world. Moreover, every object in the virtual world is interoperable and may have various scripted, interactive behaviors. In other words, the virtual world server has a script engine that allows the user to upload a script, which contains the behavior of an object, to the server. Therefore, when a user interacts with an object in the virtual world, the script engine interprets its script, executes actions, and represents them to the users via a virtual world viewer. Such functionality enables trainers to develop flexible training content. Trainers can arrange the positions of buildings or place an object in the training field. Afterwards, trainers can build scripts for each object to determine its behavior when a trainee interacts with it during the training course.

However, MOSES, as well as other virtual world applications, has limitations on extending training content. In particular, the script engine does not support the creation of training courses that are based on accurate simulation results. Yet, if a trainer wants to build a realistic training course for an evacuation process, the script engine should support the realistic simulation of the target environment or the systems, such as the propagation of a chemical cloud after a bomb detonates or the propagation of a chemical cloud based on geographical features and environmental factors. Moreover, even if the script engine can support a realistic simulation, the computation of such a realistic simulation can burden the application servers, so that the servers cannot service the trainees.

2.3. Federation Development and Execution Process

In the modeling and simulation fields, HLA has been approved as an IEEE standard to specify interoperating, heterogeneous simulations within distributed environments. In this standard, a standalone simulator is called a federate, and the set of federates that comprise a larger system to achieve the same purpose is called a federation (IEEE 1516-2010). If a simulator is compliant with HLA protocols, we call it an HLA-compliant simulator. The Federation Development and Execution Process (FEDEP) is a recommended development process used to develop HLA-compliant simulators and federations (IEEE 1516.3-2003). FEDEP is a standardized and recommended process for developing interoperable, HLA-based federations. Figure 1 shows the phases of FEDEP.

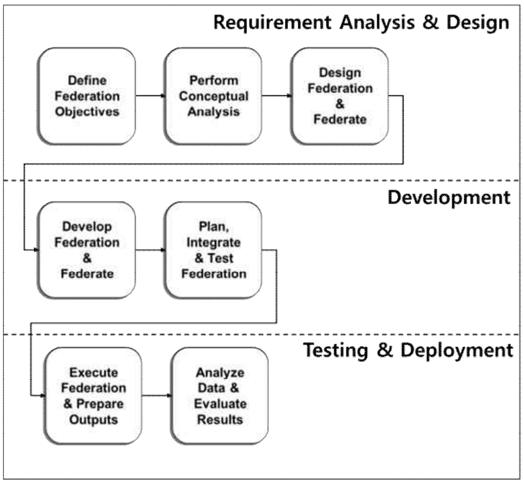

Figure 1: Phases of Federation Development and Execution Process

As shown in Figure 1, a developer should first define the objectives and requirements of the federation and confine the scope of the federation's development to the identified requirements. When the objectives of a federation are fixed, a developer should perform a conceptual analysis of the target system. Then, the developer will design and implement the federation and each federate. In this phase, the developer should identify the input/output data of each federate, in order to create the Simulation Object Model (SOM). The SOM contains the types of data that the simulator will exchange during the simulation. The Federation Object Model (FOM) is the set of SOMs that constitutes the federation data. After identifying the dataset, the developer has three options: utilizing an existing federate, develop a federate from scratch, or modify a legacy simulator into an HLA-compliant simulator. After the federates are implemented, the developer may integrate them into a federation and test it. After integration and testing, a user executes the federation and analyzes the data. Finally, the federates are revised based on the analyzed results.

However, the FEDEP is insufficient for developing a federation among the serious game and the constructive simulations for several reasons. First, a serious game has usually been implemented already; thus, it is almost impossible to modify the game application to support HLA protocols. Second, the time units of the serious game and the constructive simulator may be different; thus, the developer must tune the time resolution between them. For example, the default time unit of a constructive simulator may be hours, but the default time for a serious game may be milliseconds.[1] Therefore, time synchronization between a serious game and constructive simulators is different from interoperation between simulators. Third, standard distance values that differ between the serious game and the constructive simulator should be calibrated. For example, the standard distance value of a constructive simulator can be in kilometers, and the space of the training ground can be 100 m^2 or more. However, such a training ground will hinder the training experience in a serious game. Usually, the designer of a virtual training ground wants to maximize training; therefore, training grounds are usually relatively small and bounded. Therefore, the developer should consider and regulate the values between the constructive simulator and the serious game.

In the next section, we will propose a methodology for interoperation between a serious game and a constructive simulator that takes the aforementioned problems into consideration.

3. PROPOSED SERIOUS GAME DEVELOPMENT METHODOLOGY

Before moving to the central part of the MSGDEP, we must identify the components of the SGMT and their roles. The proposed SGMT consists of an existing serious game that provides virtual battlefield situations for training and several constructive simulators to describe the situations in detail. Let us suppose that trainees exercise MOUT (Military Operations in Urban Terrain) using the proposed SGMT. In this case, the existing serious game provides battlefield situations, such as the number of soldiers and the constructions that are involved, while the constructive simulators compute numerical calculations, such as atmospheric diffusion and damage assessment. During a simulation, the calculations of the constructive simulators are reflected in the serious game. Consequently, the separation between the existing serious game and constructive simulators enables to reuse individual components, and trainees can experience expandable battlefield situations easily by communicating with various constructive simulators in the existing serious game. From the viewpoint of system engineering, the SGMT is considered to be a system of systems (SoS). Therefore, developing a federation that consists of a serious game and a constructive simulator and building a system of systems are alike.

In our previous research, we proposed a System of System Entity Structure (SoSES) and Federate Base (FB) framework to manage federates and synthesize the federation (Kim et al., 2013). When a developer wants

[1] The time unit of a constructive simulator is logical time; thus, the designer of the simulator can decide the unit time of the simulator.

to build a federation, the SoSES/FB framework supports the developer in synthesizing the federation, based on its objectives. The SoSES denotes the structure of the federation and helps the developer to choose which federate will join the federation. After the user selects a federate, the framework automatically bring federates from the FB and synthesizes a federation from them. In other words, the SoSES is a blueprint of a federation, and the FB is a repository for federates.

However, SoSES/FB is not suitable for developing or extending a serious game via interoperation. Unlike typical federation development, SGMT development should consider the user's behavior and the time synchronization between a game and its simulators. Generally, when the designers of a SGMT build a virtual training field, they arrange the virtual objects to maximize the training experience. As a result, the size of a virtual training field is relatively small, and the placement of the virtual objects leads the user to acquire virtual training experience. On the other hand, the objective of a constructive simulator is to acquire reliable simulation results from the simulation models. Therefore, the developer should narrow the gap between the serious game and the constructive simulator, in order to build and extend the SGMT via interoperation.

Figures 2 and 3 show our proposed development methodology. First, the developer should consider the objective of the federation and perform conceptual analysis. During the conceptual analysis, the developer must consider which serious game application and constructive simulators should form a federation. In this phase, the developer decides to develop a game agent or federate from the beginning or utilize existing federates from the FB. Figure 2 shows the former process, and Figure 3 shows the latter process. The differences between FEDEP and the MSGDEP can be characterized by the federation synthesis, game agent development, and parameter tuning phases. In the following section, we will explain each phase in detail.

3.1. Federation Development Process for SGMT

As shown in Figure 2, the proposed development methodology extends the FEDEP. The differences between the FEDEP and the federation development process for SGMT are in the game loop analysis, game agent design, game agent development, and parameter tuning phases.

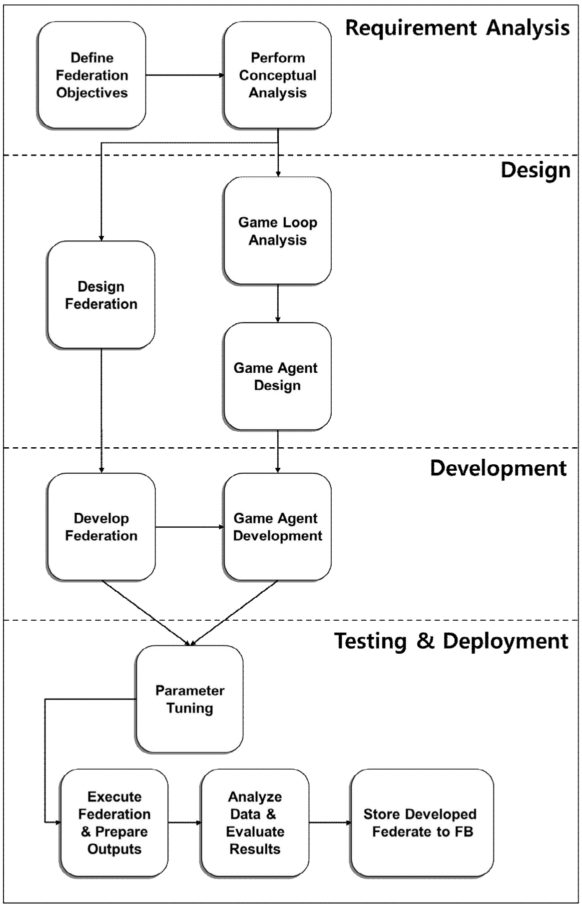

Figure 2: Federation Development for Interoperation Between Serious Game and Constructive Simulator

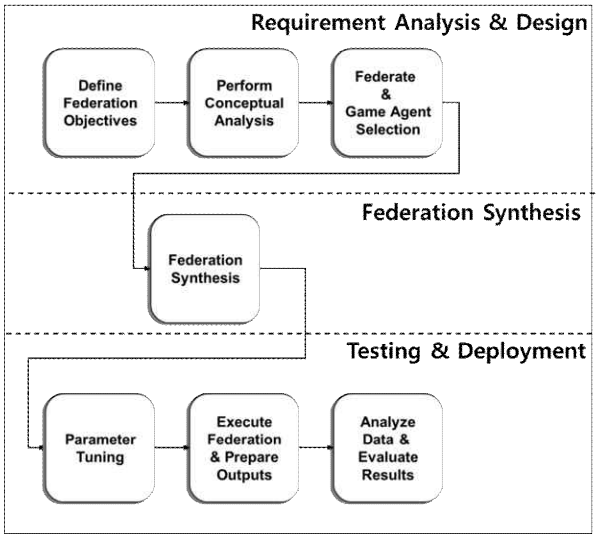

Figure 3: Federation Synthesis for SGMT Development Using HLA/RTI

3.1.1. Game Loop Analysis

In order to interoperate a constructive simulator and a given game application, the developer should identify the necessary information for the constructive simulator and game application. For example, the constructive simulator should know the position of the user participating the virtual training, and the game application should know the states of the users, which are determined by the constructive simulators. In order to acquire such information, the developer should understand the *game loop* of the game application. As described by Valente et al. (2005), input data acquisition, data processing, and rendering occurs simultaneously while the game is running; in order to handle the process, the game loop is made up of the *read player input*, *update*, and *render* stages.

Therefore, in order to interoperate a serious game application and a constructive simulator, the simulation results from the constructive simulator should be reflected before the render stage. In order to reflect the simulation results before the render stage, the developer has two options: modify the server structure of the serious game or modify the client program of the serious game. For example, the former option may involve inserting additional game logic into the update stage, while the latter option may reflect the simulation results during the read player input stage. Between these two options, the former option may be more suitable for implementing interoperation features into the serious game; however, the latter option may be more suitable for cases in which the server and the client of a serious game have already been developed.

In this study, we assume that the client and the server of the serious game have already been developed. To tackle this problem, we built a special client for a serious game application called the Serious Game Agent (SGA), so that the client subrogates the constructive simulator to reflect the simulation results to the serious game. Therefore, in the game loop analysis phase, the developer should understand the protocol between the server and client of the serious game.

3.1.2. SGA Design/Development

When the analysis of the game logic of a serious game application is finished, the developer should design and develop the SGA. As mentioned earlier, the SGA is a gateway for the game to interchange information between constructive simulators and a game. The objectives of the SGA are to manage the mapping between the information from the serious game and the information from the constructive simulator, and transfer the information to the other side as quickly as possible. Therefore, the developers of the SGA may focus on how information is managed between the game and simulators, rather than rendering the objects in the serious game. Figure 4 shows the architecture of the SGA. The HLA/RTI controller of the SGA handles the communication between the HLA/RTI and the SGA. In particular, the HLA/RTI controller controls the invocation of HLA services and handles the HLA service callbacks. Correspondingly, the service protocol between the server and the client of the serious game is implemented in the serious game connector. Then, the SGA transfers information from the constructive simulator to the serious game, based on the information mapping tables, and vice versa. Finally, when the development of the game agent is finished, the developed game agent is stored and federates to the FB.

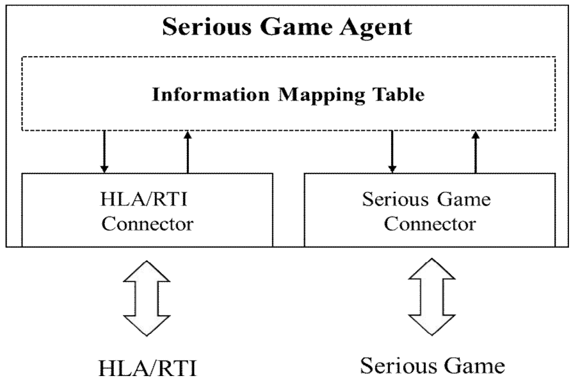

Figure 4: Architecture of a Serious Game Agent

3.1.3. Parameter Tuning

Since the game application and the constructive simulators are different, the developer should tune the parameters. Before we discuss this phase, we need to analyze the characteristics of the serious game and the constructive simulators. The objectives of a constructive simulator are to measure and analyze the performance index of a simulation model. A developer designs and implements the constructive simulator to obtain reliable simulation results. Therefore, the simulation time and simulation space must reflect the real world.

However, the scales of time and the space are relative to the users. For example, the speed of a vehicle in the simulator may be denoted as km/h, which is important because the data affects the simulation results. On the contrary, the trainers of a serious game will not consider the exact speed of a vehicle; they may regard the relative speed as more important. Moreover, the distances between objects may differ. If the simulator uses a different distance scale in the serious game, the simulator may generate unintended simulation results. In contrast, if the serious game utilizes the distance scale of the simulator, the trainee may become bored, because implementing a training field with real scales will generate an enormous virtual training field. As a result, the developer should consider the scales of time and space and tune the parameters iteratively, until the requirements and implementation of the federation are met.

3.2. Federation Synthesis Process for SGMT

As shown in Figure 3, the differences between the federation development process and the federation synthesis process for SGMT are in the *federate and game agent selection* and *federation selection* phases. The management structure of the federation and synthesis algorithm was detailed by Kim et al. (2013). After the selection and synthesis phases are finished, the developer should tune the parameters.

4. CASE STUDY: NUCLEAR/BIO-CHEMICAL EVACUATION TRAINING SIMULATOR

This chapter will detail our empirical research. In order to generate dynamic situations during serious gaming, we utilized the virtual world application In-World Editor as a serious game and the chemical diffusion simulator as a constructive simulator. First, we will introduce the serious game application and the constructive simulator. Then, we will share our experience about interoperating both of them. Finally, we will share what we learned during our empirical research.

4.1. In-World Editor

In-World Editor is a virtual world application based on the Unity 3D Engine and Photon server application (Unity 3D, 2013; Photon Network Engine, 2013). In order to provide a sense of reality within a well-built virtual training environment, the user can rearrange the objects during gameplay. Moreover, the application supports scripts, which allow objects in the virtual world to interact with the users. In addition, it supports interactions between multiple users. Each user shares a virtual training environment and trains with other users through each client. They can allocate virtual objects to the field and arrange the positions of objects that other users have allocated. Figure 5 shows a screen capture of the In-World application.

Figure 5: In-World Editor

To provide an immersive experience for users, this application provides some functionality to build virtual training environments. First, the user can allocate and remove various objects freely, such as buildings, cars, trees, sensors, bombs, and so on. Figure 6 shows the object allocation in a virtual training environment. The server of In-World Editor manages the assets, and the client shows them when the user of In-World Editor wants to allocate virtual objects to the virtual world.

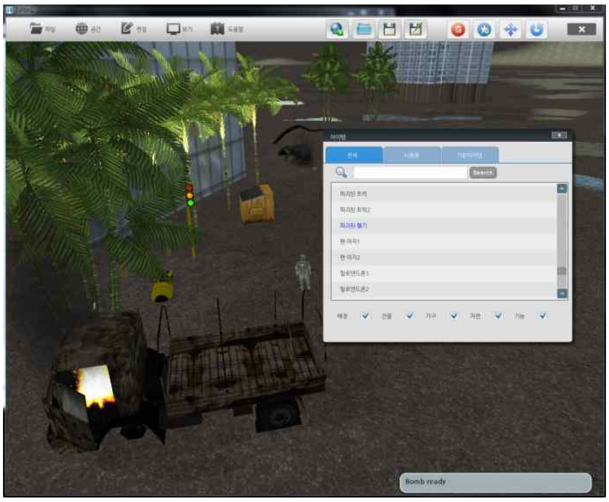

Figure 6: Object Allocation

In addition, users can interact with the allocated virtual objects. For example, users cannot go through obstacles that have been allocated onto a road. Therefore, the trainer can lead the trainee to the training content. Moreover, In-World Editor supports allowing the trainer to plant a bomb, and the trainer can detonate the bomb at any time. Using these objects, a trainer can create a well-built virtual training environment. Additionally, In-World Editor supports administrative functionality. The trainer can use script commands to control the virtual environment.

Figure 7: Interact with Object (detonate bomb)

In-World Editor provides interaction between users and the virtual world through 3D graphics; however, it cannot provide realistic simulation results to trainees. For example, if the trainer wants to build a training scenario in which the trainee must handle an evacuation due to chemical warfare, the developer should modify or insert the game logic for chemical warfare. In order to extend functionality without changing any of the game logic for In-World Editor, we utilize the chemical diffusion simulator by interoperating them.

4.2. Chemical Diffusion Simulator

The chemical diffusion simulator is a constructive simulator that calculates the distribution of the chemical compounds over the various geographical features. To obtain a realistic distribution of the compounds that considers the effects of solid walls and wind, the constructive simulator utilizes a numerical Computational Fluid Dynamics (CFD) model (Blazek & Jiri, 2001). Utilizing CFD models, the user of a constructive simulator can analyze various distributions of chemical compounds after a chemical detonation. Figure 7 shows a screen capture of the constructive simulator calculating the distribution of the chemical compounds.

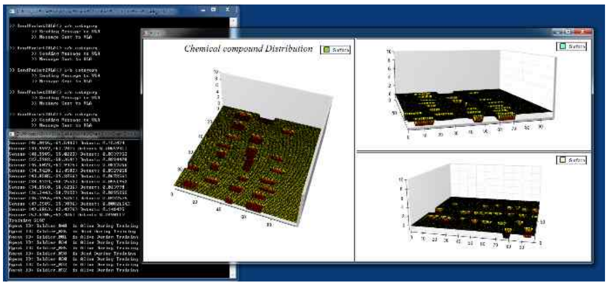

Figure 8: Chemical Compound Simulator

The CFD model discretizes the virtual space of the game into grids and solid boundaries and then computes the states of the grids iteratively based on the governing equations, boundary conditions, and states of the neighboring grids, as the simulation time advances. In the chemical diffusion simulator, the CFD model uses Roe approximate Riemman solvers to update the states of the grids, such as their density, velocity, and energy, based on the Euler equation for the governing equation, as well as solid walls and characteristic boundary conditions for the boundary condition, as seen in Figure 9 (Roe, 1981). When a chemical bomb explodes in the constructive simulator, the state of the grid where the exploded bomb is located changes, and the density of the chemical compound increases. From that point, the updated states influence the states of all neighboring grids during iterative computing of the CFD models. The distribution of chemical compounds is calculated based on the chemical compound's density and pressure, and may vary according to the bomb type and the environment.

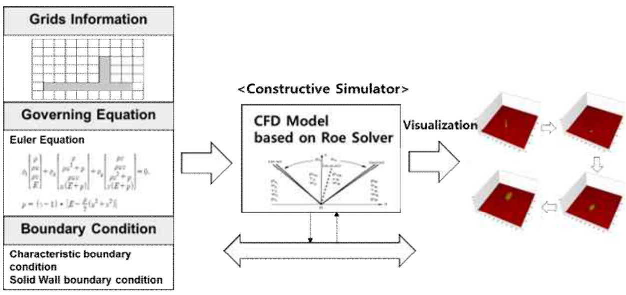

Figure 9: Boundary Condition for the Simulator

4.3. Interoperation Between the Virtual World Application and Constructive Simulator

In this section, we will introduce the technologies applied during the interoperation between the game application and the constructive simulator. Figure 10 shows the documents used during the *game loop analysis* phase. In order to speed up the pace of development, we utilized PowerPoint documents to determine the data structure between the constructive simulator and the serious game.

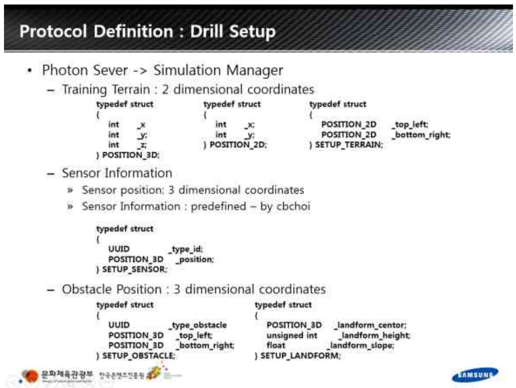

Figure 10: Communication Documents for Drill Setup

Figure 11 shows the calibration concept during the *parameter tuning* phase. The left portion of Figure 11 shows the geographical features that the trainer has arranged. In order to control the path of the evacuation, the trainer may place more virtual objects. The right portion of the figure shows that the constructive simulator has received the geographical features from the serious game. Since every client in the game should receive information about the objects, which are allocated in the virtual space, the SGA receives the information and transfers the data to the HLA/RTI. Then, the constructive simulator receives the information and initializes the geographical features of the field. While transferring the geographical information during interoperation, the SGA discretizes the geographical data spatially.

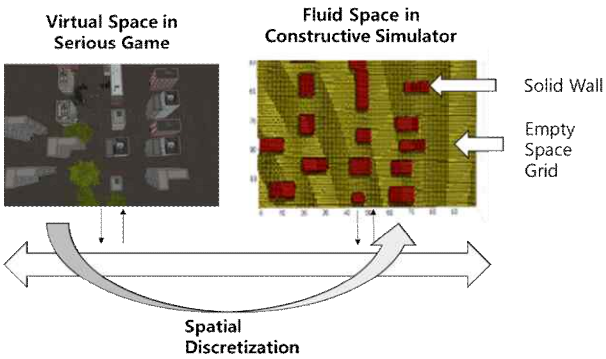

Figure 11: Chemical Compound Simulator

During the training session, the SGA continuously updated the other users' position information to the HLA/RTI, and the constructive simulator assessed live or killed states based on the trainee's chemical dosage amount. After the assessment, the simulator sent the trainee's state to In-World Editor through the HLA/RTI. Finally, we utilized the administrative functionality to make killed trainees lay down.

4.4. Lessons Learned

After developing SGMT using HLA/RTI, we gained several insights. First, depending on the demanded accuracy of the serious game, the constructive simulator can utilize various turbulence CFD models. However, several accurate CFD models cannot guarantee the timing constraints of real-time simulation because of the huge computational time required. Therefore, we had to find appropriate CFD models to satisfy the requirements of a serious game. Moreover, after we found the appropriate CFD models, we had to tune the parameters iteratively until they were appropriate for the CFD model.

Second, in order to develop a federation between the SGMT and the constructive simulator without modifying the SGMT, the protocol between the server and the client of the SGMT should be opened up to the developer. Since we are developing an SGA, which acts as a gateway to the other simulator, the developer should understand the game loop of the serious game. The problem is that commercial games do not offer open game protocols. As a result, we had a difficult time acquiring a serious game in which to develop the federation.

Third, in order to affect the user or the virtual objects during gameplay, a serious game should support administrative features or server-side scripting features. Since the serious game we used was limited for other training contents and we are extending the serious game using HLA/RTI, we could share information easily from the serious game to the constructive simulator. However, if the serious game does not provide the functionality for the user to influence the behavior or states of virtual objects and other users, then it will be very limited in helping trainees to gain training experience. For example, before we discovered In-World Editor's administrative functionality, we displayed the simulation results in the chat area. Because of its functionality, we chose this virtual world application over several other applications. The virtual world application can make up and arrange virtual training fields easily, and supports server-side scripting, so that we can influence the users and the virtual world objects easily.

5. CONCLUSION

Extending a serious game for military training can be tedious and difficult work. In order to support developers in extending serious games more easily, we have proposed a methodology to develop a SGMT using HLA/RTI. The methodology extends the SoSES/FB framework and its development process. The main characteristic of the methodology is that, when a game agent and a constructive simulator are provided, a developer can easily synthesize the federation using the SoSES/FB framework.

In case a game agent or a constructive simulator does not exist, the methodology provides a means to develop a federation. We expect that the proposed MSGDEP will assist developers who want to extend existing game applications to serious games, or extend existing constructive simulators to training simulators.

ACKNOWLEDGMENTS

This work was supported by the Defense Acquisition Program Administration and the Agency for Defense Development under the contract UD110006MD, South Korea.

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THE EDGE DECISION SUPPORT FRAMEWORK
"Emergency Management Training and Support to Operation"

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ABSTRACT
Organizations need agile Command, Control and Coordination frameworks that support a rising real-time flow of information and visualization with embedded training features. Decision makers and their teams are increasingly likely to be geographically distributed and composed of members of different organizations. One inherent problem is the limitation on sharing and visualizing time-critical information due to current informational boundaries.
The authors' research focuses on the design of an Edge Decision Support Framework (EDSF) and a Common Synthetic Environment Service (CSES) that provides shared awareness to a distributed group of users who operate as a team in a "synthetic" Command Center. It focuses on the concept, design and development of an integrated platform that can be used for training through operations and is suited to supporting Civil-Military Cooperation through its mechanisms for crowdsourced situational awareness and Command and Control supporting remote collaboration.
This paper addresses various issues including security, bandwidth and network reliability challenges and illustrates the potential for an approach that enables civilian and defense services to be trained to cooperate through web and mobile applications via interoperable information exchange models.

Keywords: Training, Decision Support Systems, Crowdsourcing, Emergency management.

1. INTRODUCTION
The impact of social media's role in the "Arab Spring", and the recent "Kony" campaign, is being felt globally, affecting developed and developing nations in a variety of ways. While these social media-driven movements demonstrate the potential for rapid mass politicization and mobilization of communities facilitated by social media communication without traditional political organizational structures, there is no certainty of the applicability of any "direct lessons" to other contexts (Stepanova K. 2011). Though the focus of this paper is on the possibility to build more agile and collaborative organizational systems with these technologies, the authors note that harnessing these technologies within organizations and government is likely to cause significant transformation over the longer term.

The concept of crowdsourcing is recent, but researchers have already looked at its application within decision support systems. Social networking technology used within organizations, known as "Social Enterprise" systems, has demonstrated mass collaboration can be used successfully internally and in external communication to generate new ideas, facilitate workflows and develop new processes, build cross-functional teams and better addresses the needs and desires of customers (Self R. L., 2010). Investigation is now required to determine the impact crowdsourced intelligence (and its analysis) will have on command and control (C2) organizations to support decision making processes.

The authors believe that ubiquitous mobile phone coverage, access to wireless Internet and intuitive communication software, available on mobile devices and desktop PCs, makes a simple but deceptive idea seem possible: that large groups of people can be smarter than an elite few. There is an underlying assumption within many crowdsourced intelligence projects that crowds can be "smarter" than traditional analysts at solving problems, fostering innovation, coming to wise decisions, and even predicting the future (Surowiecki 2004).

Crowdsourced information's potential to support faster decision making has led the authors to define a framework called the Edge Decision Support Framework (EDSF) that aims to enable safer decision making processes in a crowdsourced environment.

The initial prime use case for EDSF supporting decision making is an emergency and incident management scenario. The authors make several assumptions about the initial use case environment:

- The crowd is a filtered crowd consisting only of members of the inter-services organizations involved in a cooperative civil-military (CIMIC) cooperation scenario.
- Information can be verified by multiple independent sources.
- The "elite few" are members of cross-functional teams, and decision makers, who

are remotely connected via a reliable network connection.

- Decision-makers use innovative collaboration methods such as using a mix of synchronized web applications and virtual world technology that visualize a common understanding of the common operating picture including verified live data coming from the crowd and data collection systems such as geo-data and UAV video feeds.

This paper presents the description of the state of the art where: Social Decision Support Systems are defined based on the use of social networking technology within a crowd; and Edge Command and Control systems are defined by the NATO maturity model methodology.

This paper then investigates how social network technology and crowdsourced information can be used to expand the concept of a Social Decision Support system. A potential CIMIC environment scenario is outlined, then the authors propose the model, architecture and main components of a Decision Support Framework defined by an Edge C2 maturity model: the "Edge Decision Support Framework" (EDSF) presents an innovative solution integrating web and virtual worlds technology for distributed decision makers with a mobile application designed to enable a crowd of participants to provide decision makers with real time information and imagery from anywhere they have access to the crowd.

2. SOCIAL NETWORKS, DECISION SUPPORT & COMMAND AND CONTROL SYSTEMS

The history of Decision Support Systems (DSS) goes back to 1945 (Power, 2002). They can be classified based on their decision process emphasis (Power, 2007). The main classic types are:

- Model driven
- Data driven
- Document driven
- Knowledge driven
- Communications driven

A recent interesting model of classification of a DSS, looking at its maturity level, can be achieved through the NATO NEC Command and Control Maturity Model (N2C2M2). If we think of a C2 system as a decision support tool it is possible to imagine how a disparate set of independent entities (yet inter-dependent) that form an independent "collective" (a "community of practice") can focus and agree on decisions using this tool jointly in a remote and distributed environment. In this case the C2 environment can serve a collective-supported decision making function. This function has to be based on variations in the allocation of decision rights to the collective, patterns of interaction and information sharing behaviors among the entities of the collective and the distribution of information among these entities (NATO SAS-65, 2010) (Figure 1).

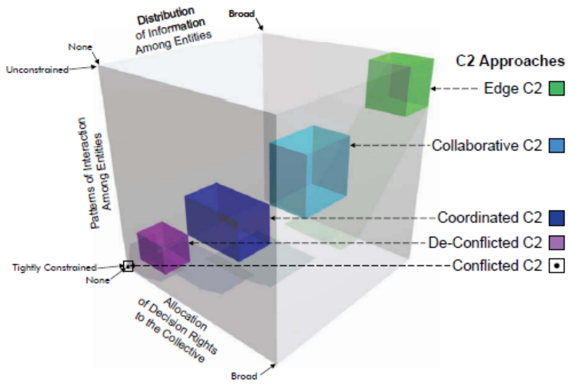

Figure 1. N2C2M2 - C2 Approaches and the C2 Approach Space

A broad distribution of information among entities with unconstrained patterns of interaction among them and a broad allocation of decision rights in the collective depict what is called an Edge C2 Organization.

The authors believe that social networking and crowdsourcing are potential methods of setting up and expanding an agile Edge C2 Organization while supporting agile decision making processes important to a CIMIC scenario.

2.1. Social Decision Support Systems (SDSS) and Social Network Analysis

Today, one of the most promising trends in the decision support and Command and Control areas seems to be social support for decision making. Access to the social support tools can be enabled by utilizing web technologies that are easy to access via network-connected mobile devices.

The authors investigated the state of the art of concepts related to a Social Decision Support System (Turoff et. al., 2002) and a Socially Supported Decision System *(SSDS) (Garrido and Faria, 2008);* then analyzed a Social Decision Support mechanism based on the friends networks concept (Yung-Ming Li and Yi-Lin Lee, 2012) and have now designed and developed a prototype toolset that supports the new framework. Furthermore, it will be utilized in future research to test the validity of this approach as framed by both perceived effectiveness as well as current theories of Social Decision Support. These theories consider the inter-relationship of group composition, group influence processes, individual preferences and collective responses.

If we define social decision making as the process that takes every individual's local decisions and generates a collective response, then in terms of group decision making, two aspects are important: normative and informational influence. Normative influence is based on the desire to conform to the expectations of others, and informational influence is based on the acceptance of information from others. These aspects are also true when applied to problem-solving tasks and collective recall.

A social decision support system (SDSS) allows users in a network-based environment to form a decision group and participate in a collaborative decision making process. In Edge C2 organizations related to a CIMIC environment, it is assumed that there are two main groups: the elite few who are the decision makers and their close staff of specialists and analysts, and everybody else who is participating (the "crowd").

Given the effect that crowdsourced information can have on decision makers, this project may need to demonstrate how it can understand each member of the crowd by recording their otherwise invisible social and spatial relationships (based on GPS information) over time and provide an index of the timeliness and quality of any unique information that each member provides.

Social network analysis, as a methodology for understanding complex patterns of interaction is primarily focused on discovering friend connections, leaders, influential people and friends (Yung-Ming Li and Yi-Lin Lee, 2012).

By leveraging social networks analysis over a period of time, effective automated analytics may provide an indicative value of the trustworthiness and value of every piece of crowdsourced data (whether that be an individual's contribution or aggregated information from multiple sources) for the decision making process. Data that has a low trustworthiness can be automatically excluded from the main data source (the "Common Synthetic Environment Service") and instead can be included in a counter-intelligence database that is available for further analysis. This automated approach supports increasing the volume of real time information and so is an important component that must be in place before broadening the concept of the "crowd" to include civilians on any large scale. We believe that large scale crowds will be part of future EDSF systems.

2.2. Edge Command and Control Systems

Virtual C2 systems should provide embedded decision support functionalities through suitable "user friendly" decision support tools that are integrated throughout the C2 environment. Latest trends in the development of C2 tools are the use of Intelligent Agents (IA) and remote collaboration where social networking and crowdsourcing can be viewed as the most extreme forms of remote collaboration.

According to NATO's N2C2M2, an Edge C2 system is basically characterized by a robustly networked collection of entities having widespread and easy access to information, sharing information extensively, interacting in a rich and continuous fashion, and having the broadest possible distribution of decision rights. While the objective of an Edge C2 is to enable the collective to self-synchronize, in an edge organization there is a configuration of the participants that have no predefined structure. Participants are not assigned to teams or roles, and every participant has access to all information sources (NATO SAS-65, 2010). The authors outline an Edge C2 system that can be defined as a crowdsourced environment where a dispersed leadership and a socially networked crowd take part in the decision making processes, providing valuable feedback and opportunities by rendering timely and relevant information. The application of the concepts related to Social Decision Support systems and Edge systems and organizations can be successfully applied to develop what the authors called the Edge Decision Support Framework. This framework can benefit from information provided by a crowd to support a timely decision making process in an emergency management environment.

3. CIMIC EMERGENCY MANAGEMENT SCENARIO

To define the needs and requirements for a Social Decision Support Framework to enable Edge C2 Organizations, the authors proposed an emergency and incident management scenario where both civilian and military organizations, with very different cultures and agendas, must work together to share information beyond a negotiated shared networks environment (Dekker 2002). In this information environment, military and civilian C2 headquarters have to communicate with each other to share information in a shared synthetic environment. This 'peer to peer' style arrangement is common to emergency services, as each unit or assets will tend to cover a geographical area and work within that area whilst communicating with peers in other areas. (Houghton J. R. at all. 2004).

The aim is then to outline potential solutions that will best fit the needs of emergency management plans and requirements focusing on the following challenges (Office of the Emergency Services Commissioner, 2012):

- Historic emergencies: provide easy online tools for data recording, event and analysis timelines, event and response visualization that can be made accessible based on the roles and privileges provided to decision makers, analysts, researchers, partner organizations and the wider public citizens

- Working with community groups before, during and after emergencies: the framework must provide methods to actively support the review of emergency services activities and an organization's emergency management response
- Joint services collaboration and events management, coordination and control: in a government context this includes defense forces, firefighter, healthcare, civil protection forces, police and volunteers. In an organization's context, this includes all its suppliers, staff, partner organizations, government services, media/PR and other organization and communities affected in the event.

The proposed Edge Decision Support Framework (EDSF) would enable organizations to work separately and with other organizations, governments, emergency services, the media and industry representatives. This approach is likely to lead to a wider range of issues to be faced sooner which may raise the tempo of the operation and necessitate a coordinated response. If achieved, the response will potentially better address community needs and concerns throughout the planning, response and recovery cycle, which may reduce the overall cost and duration of the response.

4. THE EDGE DECISION SUPPORT FRAMEWORK (EDSF)

A decision support framework enables an Edge Organization to better leverage human resources (cross functional teams) creating self-synchronized relationships between subordinated, parallel and upper levels of command by gathering feedback, orders and distributing tasks to the assigned assets (Biagini and Turi, 2011).

4.1. The EDSF Concept

The authors believe that applying the N2C2M2 maturity model principles and leveraging the knowledge and interest of large groups of people will affect the way decision making processes are supported (such as using concepts from crowdsourcing) so that a traditional command and control environment can transform into an Edge Organization. This demands an organizational shift and it also requires individuals in the organization to lead and interact differently. Creating new practices, norms and strategies will further embed new behaviors into the organization (Self R. L., 2010). In the opinion of the authors, this kind of evolution may depend on new technology, but must be driven by leadership towards a new culture. In that case, Information and Communication Technology (ICT) solutions have to support the shift in organizational culture. This process will be accelerated by providing easy to use, efficient tools that are widely adopted and properly secured.

From an ICT point of view, the culture change could be enhanced by the development of a set of tools capable of enabling reliable C2 processes across potentially distributed teams who may have limited and unreliable access to network and communication connectivity.

To enable greater reliability during disasters where existing mobile networks and internet are temporarily disrupted, several approaches are suggested to be used concurrently:

- Applications should support offline usage. For instance, web-based tools can utilize HTML5's local storage feature
- Peer to peer and wireless ad hoc networking technology may provide an alternative ad hoc network where devices can act as access points to reconnect other secured peers into any available network that can reconnect some or all team members and data services
- Support for network-wide awareness and control of available bandwidth through the peer to peer network so that critical information and media can be prioritized by decision makers to avoid message flooding when the network has limited bandwidth

The authors propose the EDSF concept as a state of the art solution that provides distributed decision makers with a shared decision making environment which offers shared situational awareness supporting:

- broadening intelligence gathering by adding crowdsourced information that has been filtered through automated analysis techniques
- distributed cross-functional teams

This concept is made possible by the integration of Virtual Worlds and web technology that visualizes the stream of event data provided by a services layer referred to as the Common Synthetic Environment (Biagini and Joy, 2012) Service (CSES).

4.2. The EDSF Architecture

The EDSF's use case is designed around the CIMIC emergency management scenario that focuses on a virtual collaborative environment to support decision-making and intelligence gathering and analysis processes between military and civilian communities of interest.

The key point of this framework is to provide an effective real-time web-based collaboration and events management tool that can be used for both simulation training and for real operations to provide users with an online solution that is easily deployed and practical in training and operational contexts. Therefore it must contain the functionality needed to match an emergency response system and a training and user performance tracking system.

The framework architecture is designed for potentially large numbers of geographically dispersed users (i.e. several communities of practice) to access the same stream of event data (including information, media and services) using a variety of devices (smart phones, tablets, computers, etc). Services plug into the architecture to extend the platform: these include GIS mapping, eLearning and analytics. (Figure 2).

The main components of this framework are:

- The Common Synthetic Environment Service
- The Virtual Command Center application
- The Citizen 2.0 application

Current systems in the emergency management field are complex, non-web-based, non-user friendly and lack multi-community structures needed to bridge multiple organizations into a common transparent decision making process. Other challenges are: the download and installation of software and web browser plug-ins is forbidden by most ICT security administration policies; and, there are network constraints that limit the bandwidth in mobile wireless networks that can cause high call volumes and uncontrolled information and media sharing to wipe out bandwidth and render the mobile networks useless.

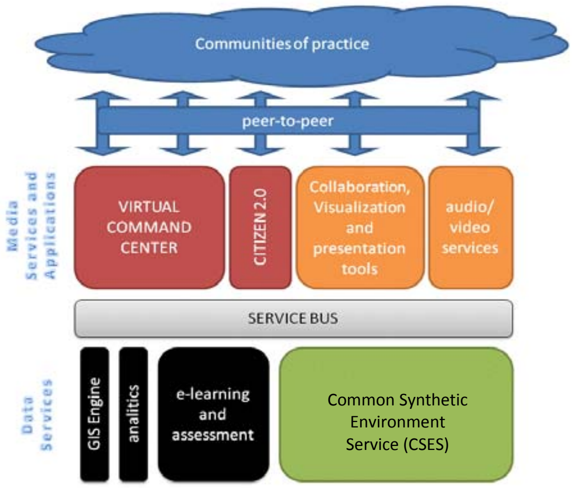

Figure 2. EDSF Architecture

This project aims to overcome these common barriers and challenges to create a new approach to remote collaboration and network management backed by a platform framework that has embedded training & assessment capabilities. The main novel features of the platform are:

- No software downloads needed to access web-based collaboration, crowdsourcing and training services
- M&S immersive simulation can be integrated using a 3D plug-in for web browsers
- Unique peer to peer networking technology can enable mobility devices (smart phones, tablets and laptops) to operate despite network outages or limited bandwidth environments
- Flexible data visualization suiting strategic and tactical views
- Web-based GIS supporting massive data sets and intuitive intelligence representation
- Secure document management where partners do not have to share files: instead they share low risk metadata that allows for information to be re-composed behind secure networks

4.3. The Common Synthetic Environment Service (CSES)

The Common Synthetic Environment Service (CSES) is a distributed metadata-driven web service. It provides access to a range of parallel data services within each organization's network. The flow of information from multiple systems can be collated and shared based on user access rights to provide the intelligence required to operate a Distributed Command and Coordination Center that the authors refer to as the Virtual Command Center where information that is available to the user can be visualized on his or her local device. The high level metadata language used by the CSES to exchange references to other data is a way to create a real interoperability layer between military and civilian information systems as the core language. The CSES enables secure information and models to remain within network boundaries but the metadata held by each network's CSES could potentially be synchronized across public and secure networks. Depending on IT policy requirements, this synchronization may be achieved via a middleman CSES service that never connects two networks together at the same time but is only accessible on one network at a time. In this way information can be provided between separate secure systems and where the metadata formats (IMML (Immersive Media Markup Language) and Metaforik formats) are used to re-compose local information and models into models within a Virtual Command Center. This approach provides an interoperability service layer between military and civilian C2 systems that also supports visualization of the data.

The CSES becomes a data discovery service and format converter that is able to receive and export in a range of languages (Biagini and Joy, 2012) (Figure 3).

The CSES is the core technology within the framework that supports the discovery of data regarding the area of operations. It is the point of access to range of underlying systems such as existing terrain databases, live data feeds, 3D model repositories and historic knowledge bases. These data sources are treated as sources of layers of information for users within the Virtual Command Center. The user's view can be based on what is appropriate for the user's function. Users that require a tactical view can see an immersive 3D representation, whereas users that require an operational view can see a text and 2D representation of the same operating environment.

In a complex information environment a fundamental requirement is comprehensible and unambiguous communication and representation of knowledge.

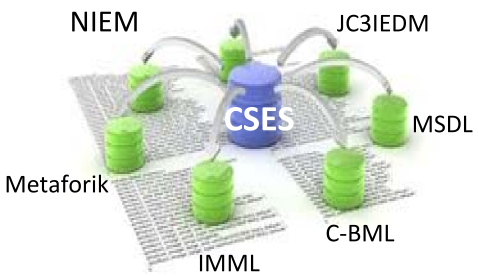

Figure 3. CSES logical architecture

This is especially critical, and difficult, as the framework can be used for multi-organization collaboration (including joint, multinational, inter-governmental and interagency services), where people have to cooperate remotely and cannot rely on common cultural reference points and assumed knowledge.

The need to develop a common operational language, that should be read and understood both by human beings, simulated entities and robots, has driven a variety of applied research activities involving scientists, academia, industry and military organizations. Valuable results include the Military Scenario Definition Language (MSDL) and the Coalition Battle Management Language (C-BML). Both languages have begun to be included in the latest Command and Control (C2) and simulation systems and are being developed by NATO and the SISO (Simulation Interoperability Standard Organization) standardization process. Both Languages share a common database model the JC3IEDM (Joint Command, Control, Consultation and Information Exchange Data Model). This model is being ratified by NATO countries under NATO 5525 STANAG. Another relevant information exchange model, suitable to be implemented with the CSES, is the USA National Information Exchange Model (NIEM) it is under development and version 3 will be released on December 2013.

As the state of the art of these research activities, the Coalition Battle Management Service (CBMS) is a technical infrastructure that enables the exchange of resources (orders, reports and requests) between C2 systems, simulation systems and robotic forces. CBMS is a collection of composable web services that can be orchestrated to support the needs of a particular federation. CBMS is currently implemented as a service oriented architecture with an interrupt mechanism, a filtering mechanism and a data distribution mechanism that can be used to support the validation, storage, search and exchange of XML based languages (Diallo et al. 2011).

Taking into consideration the state of the art of the development in this field the authors are investigating how C-BML and MSDL can be incorporated or implemented via or within a unique high level metadata XML schema to represent data coming from a C2 data model into a virtual world and vice versa. Furthermore, this metadata XML schema should align and bridge properties between both languages and above all it should make it possible to efficiently describe how related pieces of information can be visualized in a virtual world synthetic environment. A potential authors' solution is that it can be achieved by extending IMML.

Immersive Media Markup Language (IMML) is a lightweight interactive 3D XML specification that is suitable for visualizing complex multimedia, interactions and scenarios in a 3D space using a small amount of highly readable XML. IMML aims to be abstract enough that it can be used in conjunction with multiple devices and clients that use a range of 2D, 3D or Augmented Reality visualization as well as proprietary and/or open formats to render the scene on a device. A virtual world implementation supporting IMML is also suited to receiving real time updates from external services and data feeds that stimulate the visualization. Finally, IMML is easily generated or controlled by other computer languages making it a useful markup language for dynamic and adaptive immersive environments.

The proposed architecture consists of converting the database model into an XML schema, performing an automatic, reliable and efficient mapping between the schemas representing the exchanged source and target data by means of the XSLT language. (Figure 4).

Figure 4. CSES Data Exchange Mechanism logical architecture

The authors' approach has the capacity to preserve the integrity constraints of the relational schema, which allows checking the XML document for anomalies or incoherencies before updating the relational database from the XML document. It also captures the hierarchy of the tables in the target database, which guarantees that the automatically generated Structured Query Language (SQL) queries will be correctly performed. Moreover, the language converter includes a rule base allowing a coherent and secure mapping between the exchanged data sources for database integrity.

The converter needs to use an XML-based mediation framework designed to meet future needs. Therefore the framework must be ready to implement future interoperable languages beyond C-BML and MSDL.

By utilizing IMML, all virtual world information and user input can be contained in an abstract metadata format that can be rendered on the users' device to suit the users' specific visualization needs. Immersive Media Markup Language (IMML) is a specification that:

- Defines the positions and functionality for objects in 3D space, describing a 3D scene
- Is capable of being included within other IMML files as widgets for code reusability
- Defines the interaction and use of different forms of media and graphical user interface elements (3D, video, music, 2D images, text output and additional services such as VoIP)
- Defines how objects interact in a multi-user (networked) situation
- Includes interactivity between elements including real world conventions (e.g. physics) and stimulation from external systems
- Supports extensibility through scripting languages and plug-ins that can define API interfaces within IMML.

4.4. The Virtual Command Center platform

The Virtual Command Center offers a range of innovations and utilizes state of the art approaches to crowdsourcing information, integrated simulation for virtual and live training and operation support in an agile way. The concept integrates the latest virtual world simulation technology with social networking, collaboration and knowledge management capabilities. It offers significant innovation if integrated with:

- Geographic Information System (GIS)
- Peer-to-peer (mesh) networking
- Data visualization and representation of incidents
- Secure data and document sharing
- e-learning and online training assessment
- A Common Synthetic Environment Service architecture (CSES)

The Virtual Command Center provides a multi-dimensional visual environment that increases affordances and supports bringing together the best team from wherever they are around the world. This enables the creation of virtual cross-functional teams in a boundless Command Post where the people who have critical knowledge, expertise and access rights can be brought together as an effective team despite the fact that team members are physically distributed (Biagini and Joy, 2012).

This platform is built around two main views of the same environment: The Meeting view and the fully 3D Sandbox view. Both views share the same data but these are accessed and visualized with different technology and in a different way.

4.5. The Meeting View

The Meeting view is a 2.5D multimedia environment designed to support fast, easy, low bandwidth remote collaboration and decision making process using a web-based suite of tools. It can be accessed via network connected devices. A web browser is required, but no additional software or plug-in is needed to access the Meeting. The Meeting view provides chat, slide presentations, low fidelity life-like user avatar representation and participant feedback mechanisms. This view can integrate external web content such as web pages, maps, Audio/Video conference tools, audio conferencing, 3D embedded windows, advanced data visualization and data analysis capabilities (Figure 5).

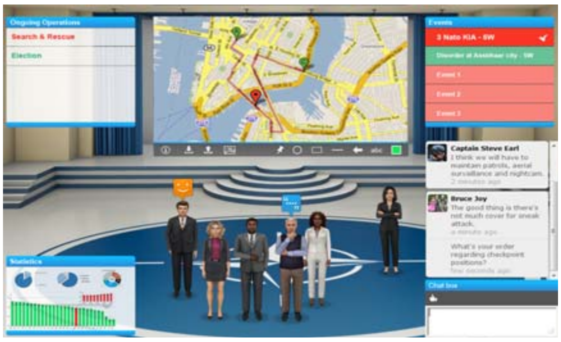

Figure 5. Virtual Command Center (Meeting View)

This suite is designed to give decision makers and analysts a simple, intuitive and agile planning and execution support tool that provides instant shared environment that supports the visualization of a shared situational awareness. It can be extended to provide access to a potentially wide range of tools compliant with IMML, Metaforik, C-BML, MSDL and JC3IEDM.

4.6. The 3D Sandbox

The 3D Sandbox is the immersive 3D virtual world environment. Though it may show the same map as the Meeting view, the 3D representation offers a more detailed view of the environment through the three dimensional views that support tactical planning.

Both the Meeting view and the 3D Sandbox view access and display customized views of the Events Stream layer and the ongoing operation layer. (Figure 6).

Figure 6. Virtual Command Center (3D Sandbox)

Using the Virtual Command Center it is possible to represent the working processes of a real world Command Center within a virtual online remote tactical operation center that is easy to access and intuitive to use. The 3D Sandbox environment could be enlarged to match the entire layout of the physical HQ that it is supplementing or representing for training purposes.

4.7. The Citizen 2.0 Application

The Citizen 2.0 application enables crowd participation within the EDS framework. It is designed for web and mobile devices so that users on smart phones, tablets and any Internet connected devices with a web browser can access the tool.

In specific operational contexts such as CIMIC operations, it is worth considering the potential benefits and risks of enabling information from civilians to be included in the crowdsourced information gathering. The mobile version of the app should be easy to use and enable members of the "crowd" to provide concise and accurate geo-located reports on what they discover and to capture and upload or stream live multimedia such as video and photos to provide useful evidence of events as well as receive inbound chat messages from command.

The app focuses on mobile devices for a number of reasons:

- The mobile device offers client-side GPS data providing accurate location data that is only partially trustworthy, but where the device can be located and the data verified by both the telecommunications service provider via cell phone tower triangulation and GPS systems themselves to confirm the validity of the GPS location data related to a report from the user of the device
- People on the scene of an event can stream live video and photo imagery and the mobile app knows if the footage is live or not
- By tracking the activity of the devices in an area where an incident is occurring and gaining information from multiple sources the EDS is able to collate the related content and enable analysts to quickly show the latest trusted data to decision makers based on crowd data that complements traditional data sources.

The application design provides a standardized "wizard" interface to take user information and generate a report in C-BML format (or equivalent) so that it can be automatically consumed within the EDS framework as data available to analysts and decision makers. This speeds up information discovery and may shift some of the analyst's tasks away from volume data entry to higher level analysis. Larger volumes of data over longer periods of time in defined formats from the same crowd of informants will expose patterns of intelligence that can provide insight into the crowd and lower the risks of counter-intelligence and misinformation. This can transform counter-intelligence efforts into rich sources of intelligence that includes networks of users, positions across time and the actual counter-intelligence imagery used to attempt to fool decision makers.

The authors focus on emergency and incident management operations where citizens could play an active role in providing live data to authorities, but are also investigating specific military operations focusing on military crowdsourcing. This military crowd could help a commander, staff or analysts to solve a specific operating problem in either a classical military situation or in a stability operation in a crisis response mission by providing a larger pool of infield data and imagery to draw upon.

There are a wide range of technical challenges to address with the use of the Citizen 2.0 application, especially in the military scenario. We propose the following capability requirements and responses:

- Challenge: Low bandwidth networks with large numbers of users offering data
- Response: Enable the command to remotely control what data is sent through the network by all of the Citizen 2.0 applications so that specific devices can stream their data to be viewed by decision makers without having other devices flood the network with data

- Challenge: Networks will be disrupted at critical times
- Response: The Citizen 2.0 application should support, utilizing all networks available to it, the users to easily activate the device as a wireless bridge so that other local devices can connect and share any network access together. Furthermore, to minimize flooding mobile data networks with reconnection attempts and using secure peer-to-peer technology to enable data to be sent through the peers, this application then should reconnect the network connectivity between the command center and all of the devices in the crowd
- Challenge: The devices in the crowd may be standard COTS phones and other portable devices so are insecure
- Response: Devices in the crowd authenticate via their device ID, phone number and its phone tower triangulation location via the telecommunications provider and its GPS location via the application. Users of the devices authenticate by logging into the application using their username and password and can be required to provide imagery including live video or photos of themselves and their surroundings. This should ensure that the analysts are certain of whom they are talking to and getting data from.

Additional opportunities exist if the server-side system supports various intelligence capabilities such as:

- Reputation profile building for each "citizen" that can provide insight into the reliability of information provided (this follows the eBay user reputation model)
- Trap misinformants and misinformation in a “honey pot” database for counter-intelligence analysis that mimics the response of the CSES but is in fact an information space specifically for content that is deemed to be or likely to be counter-intelligence
- Potential for highly localized crisis updates to flow back to citizens as alerts and to joint taskforces as alerts or even as tasks provided by the inbuilt messaging system to support actions. This has the potential to enable a potentially controllable “little brother” deterrent against insurgents within highly populated urban areas where any citizen can provide key identity information in real time.

In summary, the Citizen 2.0 app is the application within the EDSF architecture that provides all of the crowdsourced information to the CSES (Figure 7).

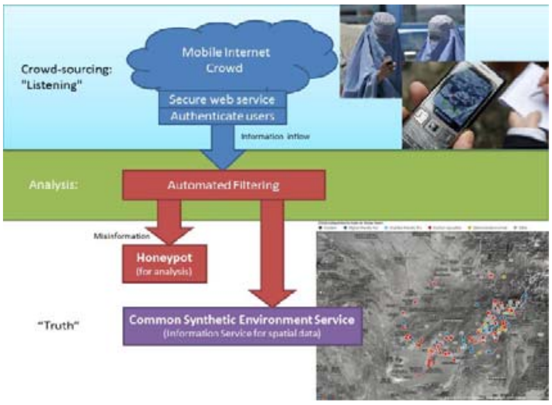

Figure 7. Citizen 2.0 logical architecture

5. CONCLUSION

The outcomes of this research established the milestone of the conceptual architecture for building what the authors call an Edge Decision Support Framework. It is based on social networks and virtual world technology assuming to be initially operated to support Decision Makers and Staff training in a CIMIC general purpose emergency and incident management environment. The prototype, now under development, can be used to build and customize applications to support decision making process and operations. This framework uses extensively “Open Source Intelligence” (OSI) through social networks, virtual worlds and mobile technologies.

The CSES forms a genuine interoperable service layer based on implementing standard languages, common data models and supporting adding more language importers and exporters when required in the CIMIC environment.

This paper presented main aspects of the research made to specify an Edge Decision Support Framework (EDSF) targeted to organizations requiring interoperable command and control environments, and the set of initial software specifications for the web-based prototype application in development:

- HTML and XML technology to reduce the IT challenge of supporting new desktop applications and/or web plug-ins that require download and installation on every device needing to access the virtual command environment
- Integration between virtual worlds, web browsing 2.0, 2.5 and 3D technologies to let users decide which of them is best suited to support their decision making process
- Capability to be used as a stand-alone system

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EXAMINING THE RELATIVE DISAGREEMENT MODEL OF OPINION DYNAMICS WITH KLEMM-EGUILUZ SOCIAL NETWORK TOPOLOGIES

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ABSTRACT
This paper presents a brief history of models of opinion dynamics and summaries of the work from the creation of the Bounded Confidence (BC) model through to the more recent development of the Relative Agreement (RA) model and finally of the Relative Disagreement (RD) model. As a result of the re-examination and correction of the original specification of the RA model given by Meadows and Cliff, and subsequent first investigation of the RA model operating within non-trivial but realistic social networks the RD model was proposed as not only an extension but a significant improvement. Given that these two highly successful approaches have been taken with the RA model, it is now necessary to present a full exploration of the new RD model operating within the same non-trivial topologies.

Keywords: relative disagreement model, opinion dynamics, Klemm-Eguiluz networks, extremist behaviour

1. INTRODUCTION

1.1. Opinion Dynamics

The term "opinion dynamics" has come to cover a broad range of different models applicable to many fields ranging from sociological phenomena to ethology and physics (Lorenz 2007). The focus of this paper is on an improvement to the "Relative Disgreement" model (Meadows and Cliff 2013b), that was originally developed as an improvement to a model designed to assess the dynamics of political, religious and ideological extremist opinions, and the circumstances under which those opinions can rise to dominance via processes of self-organisation (i.e., purely by local interactions among members of a population) rather than via exogenous influence (i.e. where the opinion of each member of a population is influenced directly by an external factor, such as mass-media propaganda). The RA model was developed with the aim of helping to explain and understand the growth of extremism in human populations, an issue of particular societal relevance in recent decades where extremists of various religious or political beliefs have been linked with significant terrorist acts.

Suppose a group of n experts are tasked with reaching an agreement on a given subject. Initially, all the experts will possess an opinion that for simplicity we imagine can be represented as a real number x, marking a point on some continuum. During the course of their meeting, the experts present their opinion to the group in turn and then modify their own opinion in light of the views of the others, by some fixed weight. If all opinions are equal after the interaction, it can be said that a consensus has been reached, otherwise another round is required. It was demonstrated by de Groot (1974) that this simple model would always reach a consensus for any positive weight. Although highly abstract and clearly not particularly realistic, this simple model has become the basis for further analysis and subsequent models (e.g. Chatterjee & Seneta 1977; Friedkin 1999).

Building on the de Groot model, the Bounded Confidence (BC) model included the additional constraint that the experts would only consider the opinions of others that were not too dissimilar from their own (Krause 2000); this is also known as the Hegselmann-Krause model. The BC model adds the idea that each expert has a quantifiable conviction about their opinion, their uncertainty, u. It was demonstrated that although a consensus may be reached in the BC model, it is not guaranteed (Hegselmann & Krause 2002). It was observed that when the BC model is set in motion with every agent having an initially high confidence (low uncertainty) about their own random opinion, the population disaggregates into large numbers of small clusters; and as the uncertainty was increased, so the dynamics of the model tended towards those of the original de Groot model (Krause 2000). Later, the model was tested with the inclusion of "extremist" agents, defined as individuals having extreme value opinions and very low uncertainties. In the presence of extremists it was found that the population could tend towards two main outcomes: central convergence and bipolar convergence (Hegselmann & Krause 2002). In central convergence, typical when uncertainties are low, the majority of the population clustered around the central, "moderate" opinion. In contrast, when uncertainties were initially high, the moderate population would split into two approximately equal groups one of which would tend towards the positive extreme and the other towards the negative: referred to as bipolar convergence.

Although these two phenomena have occurred in real human societies, there is a third well-known phenomenon that the BC model is unable to exhibit: an initially moderate population tending towards a single extreme (and hence known as single extreme convergence).

Shortly after the publication of the BC model, Deffuant, Amblard, Weisbuch, and Faure (2002) reported their exploration of the BC model and proposed an extension of it which they named the Relative Agreement (RA) model (Deffuant et al. 2002). The RA model was intended to be capable of exhibiting single extreme convergence in its dynamics.

There are two main differences between the RA model and the BC model. The first change is that agents are no longer expressing their opinion to the group as a whole followed by a group-wide opinion update. Instead, in the RA model pairs of agents are randomly chosen to interact and update. This is repeated until stable clusters have formed. The second change relates to how agents update their opinions. In the BC model an agent only accepted an opinion if it fell within the bounds of their own uncertainty, and the weight that was applied to that opinion was fixed. In the RA model however, an opinion is weighted proportional to the degree of overlap between the uncertainties of the two interacting agents.

These changes represent a push for increased realism. In large populations, individuals cannot necessarily consider the opinion of every other agent; therefore paired interactions are far more plausible. More importantly, the RA model also allows for agents with strong convictions to be far more convincing than those who are uncertain (Deffuant 2006). Thus, although the RA model is stochastic, the only random element of the model is in the selection of the individuals for the paired interactions (Lorenz 2005). As expected, the RA model was able to almost completely replicate the key results of the BC model (Deffuant *et al*. 2000).

Having demonstrated that RA model was comparable to the BC model under normal circumstances, Deffuant *et al.* then added the extremist agents to the population, to see if they could cause shifts in the opinions of entire population. An extremist was defined as an agent with an opinion above 0.8 or below -0.8 and with a very low uncertainty. Conversely, a moderate agent is one whose absolute opinion value is less than 0.8 and with a fixed, higher uncertainty who is therefore more willing to be persuaded by other agents. Under these circumstances, Deffuant *et al*. reported that there are large areas of parameter space in which all three main types of population convergence could occur. The fact that the RA model offers realistic parameter-settings under which single extreme convergence regularly occurs is a particularly novel attraction.

To classify population convergences, Deffuant et al. (2002) introduced the y metric, defined as: y = p'+2 + p'-2 where p'+ and p'- are the proportion of initially moderate agents that have finished with an opinion that is classified as extreme at the positive and negative end of the scale respectively. Thus, central, bipolar and single extreme convergences have y values of 0.0, 0.5 and 1.0, respectively.

While these findings are particularly striking, it raises the question of where the initially extreme agents may have come from. Interestingly, an answer presents itself from the field of psychology. *Social Judgement Theory* states that the opinions of others may fall within a *latitude of acceptance* in which case we may see a converging opinion update (Sherif and Hovland 1961). Conversely, opinions may fall within the *latitude of rejection*, which may result in a diverging opinion update. It is clear that the models given up to now, only one of these dynamics has been taken into consideration. Thus, the Relative Disagreement (RD) model was created (Meadows and Cliff 2013b). With this model it was shown that by utilising an analogous dynamic for quantifying disagreement as with agreement in the RA model, it was possible to replicate all three population convergences without the artificial need for extremist agents. A full specification of this model is given in the next section, as it is central to the research presented in this paper.

1.2. Social Networks

While much of the work described previously has taken place with agents represented as nodes on a fully connected graph, there is a growing movement towards examining these models under non-trivial topologies. Small World (SW) networks were introduced by Watts & Strogatz (1998), and a full introduction is beyond the scope of this paper. Suffice it to say that SW networks exhibit both low average path lengths and social clustering. Watts and Strogatz introduced an attractively simple stochastic algorithm for constructing SW networks. Nevertheless, one limitation of SW networks as models of human social networks is the extent to which SW networks have unrealistic degree distributions. In real social networks, the majority of nodes often have few connections, while a small number have very high degrees. A well-known possible resolution of this was proposed by Barabási and Albert (1999). The Barabási-Albert (BA) algorithm could construct random graphs with low average path lengths that also obeyed a power law in degree distributions (scale free networks). However, the BA model is unable to generate networks that exhibit clustering levels as high as those in observed social networks and so, although both SW and BA models were useful as research tools, neither could claim to be entirely realistic.

To construct a graph that would exhibit all three qualities observed in real social networks (short average path lengths, high clustering, and a power-law degree-distribution) algorithms have been developed that produce hybrid networks that mix SW and BA characteristics. The KE algorithm introduced by Klemm & Eguíluz (2002) is the one used in this paper. The KE model begins by taking a fully connected graph of size m, the nodes of which are all initially considered active. A network is then "grown" by adding nodes iteratively to all of the currently active nodes in the graph after which a random active node is deactivated and the newest node is assigned to be active. When adding these nodes however, with a probability μ_{KE} each new connection the node forms is assigned to a node using preferential treatment (a node with a higher degree is more likely to be randomly chosen) as in the BA model. With this addition, we see that when μ_{KE}=1.0 the resulting network is identical to the BA model and with μ_{KE}=0.0 the network is generated with topological characteristics as in the SW model. As Klemm and Eguiluz (2002) note, for values of μ_{KE} between 0.0 and 1.0, KE networks exhibit properties that are "hybrid" mixes of the properties of SW and BA networks. For that reason, in this paper we use KE networks to explore the dynamics of the RA model in nontrivially structured populations.

2. SPECIFICATION

For completeness, it is important to now provide a full specification of the RD model to allow for replication and extension work. Returning to the population of *n* agents, each individual *i* is in possession of two variables; an opinion *x*, and an uncertainty *u*, both of which are represented by real numbers. In the RA model, opinion was initially set in the range of -1.0 to 1.0, with extremists being defined as agents whose opinions lay below -0.8 or above 0.8. As the goal of the RD model was to replicate the behaviour seen in the RA model but without extremist agents, opinions may not be initially set outside the range of -0.8 and 0.8, although the maximal values are retained from before. With no extremist agents, there is no longer any constraint on uncertainties used and so they are assigned randomly using a simple method to bias agents towards being uncertain (as it is in uncertain populations that more interesting results are to be found) given by:

$$u = min(random(0.2, 2.0) + random(0.0, 1.0), 2.0)$$

Random paired interactions take place between agents until a stable opinion state is produced. Unlike in the original RA and RD models, this no longer means two agents randomly chosen from the population but instead requires taking one agent at random followed by a randomly chosen neighbour of that agent as defined by the KE network. The relative agreement between agents *i* and *j* is calculated as in the RA model by taking the overlap between the two agents' bounds h_{ij}, given by:

$$h_{ij} = min(x_i + u_i, x_j + u_j) - max(x_i - u_i, x_j - u_j)$$

Followed by subtracting the size of the non-overlapping part given by:

$$2u_i - h_{ij}$$

So the total agreement between the two agents is given as:

$$h_{ij} - (2u_i - h_{ij}) = 2(h_{ij} - u_i)$$

Once that is calculated, the relative agreement is then given by:

$$2(h_{ij} - u_i) / 2u_i = (h_{ij} / u_i) - 1$$

Then if $h_{ij} > u_i$, then update of x_j and u_j is given by:

$$x_j := x_i + \mu_{RA}[(h_{ij} / u_i) - 1](x_i - x_j)$$
$$u_j := u_i + \mu_{RA}[(h_{ij} / u_i) - 1](u_i - u_j)$$

Similarly, the relative disagreement between agents *i* and *j* is calculated by a very similar method to find g_{ij}:

$$g_{ij} = max(x_i - u_i, x_j - u_j) - min(x_i + u_i, x_j + u_j)$$

Followed by subtracting the size of the non-overlapping part given by:

$$2u_i - g_{ij}$$

So the total disagreement between the two agents is given as:

$$g_{ij} - (2u_i - g_{ij}) = 2(g_{ij} - u_i)$$

Once that is calculated, the relative disagreement is then given by:

$$2(g_{ij} - u_i) / 2u_i = (g_{ij} / u_i) - 1$$

An analogous method for calculating the agents' disagreement was chosen for ease of understanding as it also facilitates the need for calculating relative disagreement. Given that we would not want the disagreement update to occur in every instance of disagreement, as SJT suggests that this would not occur in every real-world instance of disagreement. Therefore if $g_{ij} > u_i$ and with a probability λ, the update of x_j and u_j is given by:

$$x_j := x_i - \mu_{RD}[(g_{ij} / u_i) - 1](x_i - x_j)$$
$$u_j := u_i + \mu_{RD}[(g_{ij} / u_i) - 1](u_i - u_j)$$

Note that if all disagreement updates are capped so that agents' opinions may not exceed the initial bounds of -1.0 to 1.0.

3. PARAMETERS

3.1. Size Variation

Firstly, it is necessary to analyse the variations as the scale of the model is altered. If the work is applicable for all values of n, we are often able to gain the clearest picture with large populations, as the level of noise is proportionally lower. To that end, Figure 1 shows how the overall dynamic of the model is altered as n increases with varying values of μ_{RD} with $\lambda = 1.0$.

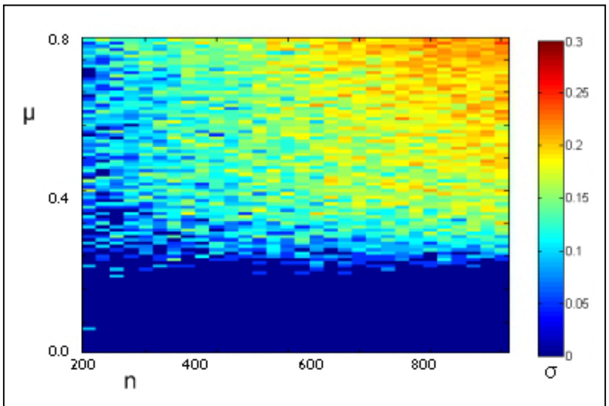

Figure 1: Average standard deviation heat map for varying values of μ_{RA} and μ_{RD} (treated as a single value μ) and n, when agents have randomised values of u, with $\lambda = 1.0$, $m = 6$, and $\mu_{KE} = 0.6$.

Here we see some very interesting, and possibly unexpected results. If we compare with the effect on the RA model (Meadows and Cliff 2013a), it was observed that as n grew, the stability of the population was increased. Much like with the later discussion of μ_{KE}, it can be seen that the influence of extremist agents is weakened because, in order to have an impact, they must rely on the subsequent influence of the moderate agents with which they interact. In the RD model, this is no longer a factor as disagreement interactions can be caused, in theory, by all agents (although in practice some agents will have such large uncertainties coupled with central opinions that they rarely cause a disagreement). Thus we see that the increase in stability typically caused by increasing n in the RA model with KE networks, is missing here.

3.2. Disagreement Probability λ

It is clear that when we set μ_{RD} to 0.0 no disagreement updates are possible, and similarly setting λ to 0.0, causes a similar result as no disagreement can lead to an update. Thus, when comparing extreme values of λ we must use low, but non-zero values, and high values of λ as shown in Figure 2.

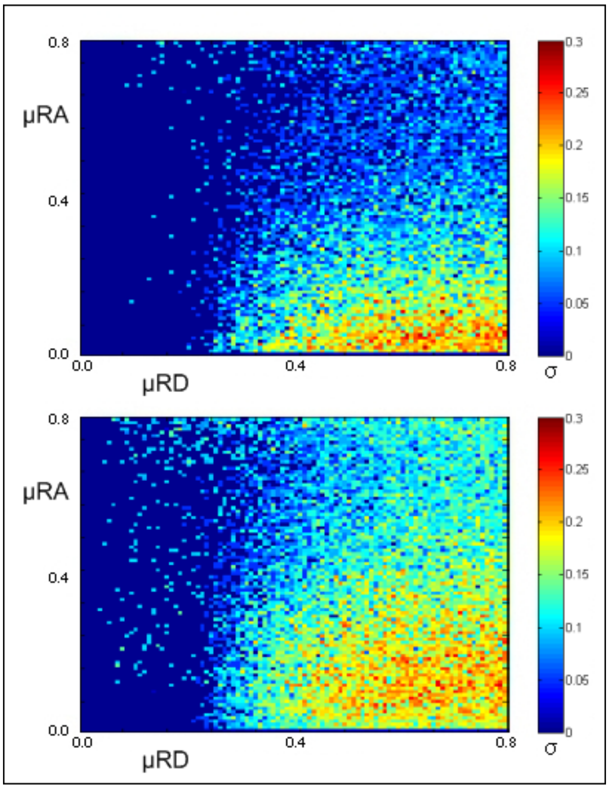

Figure 2: Average standard deviation heat map for varying values of μ_{RA} and μ_{RD} when agents have randomised values of u, $m = 6$, $n = 200$ and $\mu_{KE} = 0.5$. In the top heat map $\lambda = 0.25$ and in the bottom $\lambda = 1.0$.

As one may expect, an increase in λ leads directly to an increase in population instability. Given that when $\lambda = 0.0$ there are no disagreements that cause a repelling update occurring over the course of the simulation, we can understand that with a low value of λ there will similarly be a low proportion of repelling updates. However, with the λ set to its maximal value, every disagreement leads to an update and so we see a greater level of instability in the population. This clearly makes sense. What is surprising is that it is possible to observe the overriding importance of the disagreement update weight μ_{RD}. As before, we can see that when $\mu_{RD} > 0.2$ there is a significant increase in average instability, regardless of λ. This is interesting as it means that the effect of a disagreement must have a minimum impact in order to be influential.

3.3. Initial Network Size *m*

To further aid the comparison of the RD model with the RA model, consideration must be made to the effect of the initial network size m, from the KE algorithm. Figure 3 presents this analysis of the weight μ (where $\mu = \mu_{RA} = \mu_{RD}$) and m.

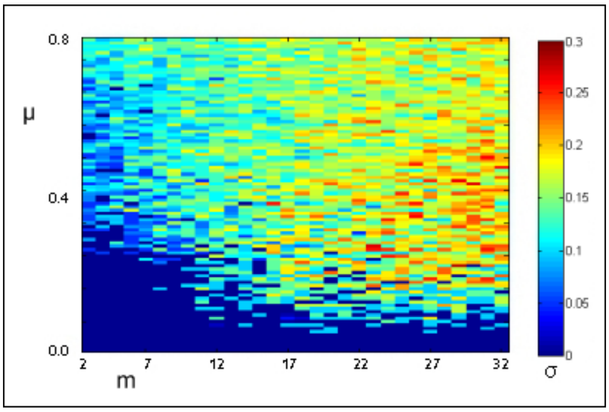

Figure 3: Average standard deviation heat map for varying values of μ_{RA} and μ_{RD} (treated as a single value μ) and m, when agents have randomised values of u, with $\lambda = 1.0$, $n = 200$ and $\mu_{KE} = 0.5$.

The first observation must be that instability grows as m increases. The nature of that growth is certainly interesting however. For very low values of m, in all cases of μ_{KE}, we can see that only when the update weights μ_{RA} and μ_{RD} are significant values can any instability be reliably inferred. As m grows, we see that the minimum values required from μ_{RA} and μ_{RD} for instability decrease. This is in line with the finding in Meadows and Cliff (2013a), which discusses how the typical agent degree is linked with the size of the m. It is the agent degree that we rely on most heavily for instability, as we have found repeated examples that show the greater the connectivity within a population the greater the opportunity for instability.

Another interesting observation is that when m increases, the "height" of the unstable region on the heat map graph shows diversity itself. With high values of μ, we see a smoother area with a lower variance, but as µ decreases, we see the data become noisier and with greater diversity in the possible variances. This unexpected result is quite interesting as it shows an interesting nuance of the RD model. The cause of this result can be explained by the fact that the weight μ was lower. When this occurs it allows for a slower convergence (as each interaction is less influential to an agent's opinion), but with a higher value of m, the agents are exposed to multiple viewpoints and as such can allow for greater swings in the possible convergence.

3.4. Mixing Parameter μ_{KE}

In Meadows and Cliff (2013a) it can be seen most clearly that the RA model operating within a clustered population was far more stable when compared to a BA network and certainly more so than a fully connected graph. Here the main reason was that the RA model's extremist agents struggled to exert their influence over longer path lengths (i.e. they only able to exert their influence over the majority of moderates through the moderates with which they are connected).

In contrast we can see very clearly in Figure 4 that the effect of clustering, although present, is severely limited. When compared to the RA model's behaviour in a clustered population however, this effect is barely noticeable.

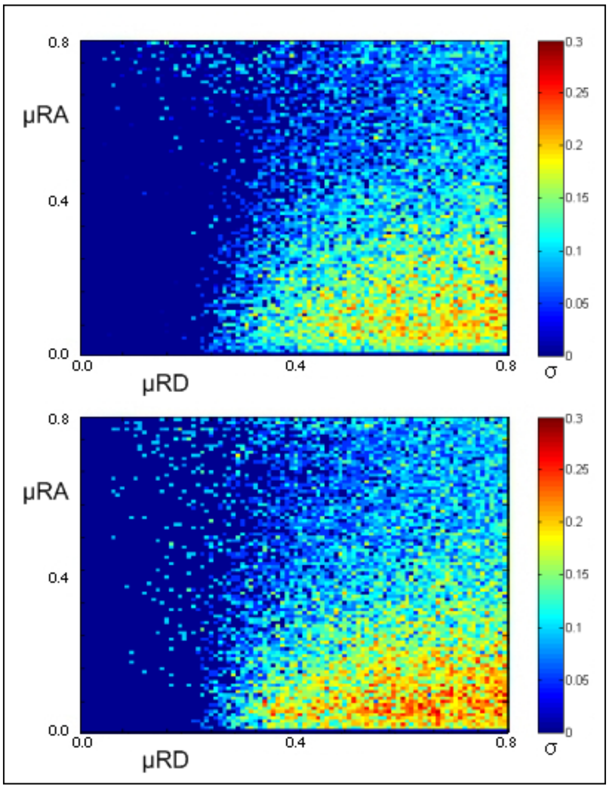

Figure 4: Average standard deviation heat map for varying values of μ_{RA} and μ_{RD} when agents have randomised values of u, $m = 6$, $n = 200$ and $\lambda = 0.5$. In the top heat map $\mu_{KE} = 0.0$ and in the bottom $\mu_{KE} = 1.0$.

The cause of this difference lies in the dynamics of the model. In the RA model, a select few extremist agents are responsible for causing overall instability, which results in their effects being severely limited when their reach is similarly cut off. This does represent an interesting insight into the dynamics of opinion exchange in real life, considering that real world social networks are themselves highly clustered. Given that it has been established that real world terrorist networks exhibit high levels of clustering and that they are a particularly resilient to external influence, the RA model's contribution to study is clearly of merit. However, this outlook fails to explain how in the real world, highly clustered populations can still lead to examples of single extreme or bipolar convergence.

The RD model offers a solution to this difficulty by the way that extremism propagates. Instead of only a limited number of agents causing instability, the instability is a product of the interaction of every agent. That is, any two agents that would otherwise be considered to be moderate can still produce instability through a disagreement. Thus we see that even in clustered populations, when compared with BA networks, agents have approximately equal average degrees, and so the effect of clustering is almost negated. The effect is not entirely ruled out because when agents are pushed towards extremism, their influence on other agents is still dependent on those that they have connections to. Therefore clustering still plays a role in maintaining a slight degree of stability in the population, but simply not to the same level as with the RA model.

While it should not be claimed that this particular difference between the RA and RD models shows an improvement over the RA model, it is an interesting and alternative insight. Instead the two models should be thought of as analysing different aspects of the same problem, with the relevant dynamic being used as required.

4. FURTHER WORK

It is clear that there is much that can be learned from the RD model with the primary focus being to further understanding the dynamics involved in the creation and propagation of extremism in a population. In particular, this application has been most closely linked to the study of terrorist development. The link between this field and the abstract work is clear, however what is currently lacking is a concrete demonstration of the parallels that validate this theoretical work. While the body of work that has been produced is too large to be applied directly to the empirical evidence, it is obvious that researchers of the abstract must find ways to establish the validity of their research. This "application work" has been largely lacking in many fields, including opinion dynamics (Sobkowicz 2009). Therefore, demonstrating real world examples of behaviours exhibited by the RA and RD models, in particular the convergence types, in relation to political and ideological extremism is the most important step for real world validation.

Although it is clear that that the given work is most easily applied to these areas, this arbitrary restriction limits the potential use of the RA and RD models. By expanding the real world applications of these models, it can be seen that many areas are in fact overlapping, although potentially unaware of their related qualities. Ignoring surprisingly related bodies of work because "it is from a different field" or because researchers are simple unaware of each other's work, is not an acceptable justification. What one field has learnt should not need to be relearnt by another. Therefore, finding and demonstrating these overlaps in knowledge is crucial and should be a main focus for future work.

5. CONCLUSION

There were many aims for this work, including demonstrating further reliability of the RD model from its earlier introduction. The most crucial element of this proof relies on the RD model operating under these constraints maintaining comparable behaviour to both the RA model under KE topologies as well as its own behaviour with a fully connected network It has been found that even under non-trivial topologies, the RD model is still capable of producing instances of all three types of convergence. While it is also clear that the disagreement interaction is more influential for instability than the agreement, both are required for single extreme convergence. Replicating the three convergences is clearly the most basic requirement that any model hoping to improve upon the RA model must satisfy. Furthermore, it is possible to see similar overall dynamics in the behaviour of the RD model when compared with its operation in a fully connected graph.

Given that the RA model maintained comparable behaviour over various networks, it is encouraging that the same can be said for the RD model.

In comparison to the RA model itself, it is clear that many of the dynamics that applied to the RA model operating within Klemm-Eguíluz networks apply also to the RD model under the same constraints. We see that in both models when the agent network is not a complete graph, population stability is slightly increased. In addition, when the social network is highly clustered the stability of the population is further increased, however, this further increase is not as great as with the RA model, because of the differences of how extremism is caused in the two models. The RA model shows that a clustered population remains stable and relatively invulnerable to external influence while the RD model shows that influence exerted through disagreements in a social network can still cause extremism.

One of the earlier aims of the RD model was to represent a further push for realism and answer the questions surrounding instability without the need for extremist agents. While it is appears more than reasonable to state that this aim has been fulfilled, it appears that there are a number of subtle differences that can be highlighted between the RA and RD models. Although it would be necessary for differences to be present, the dynamic previously alluded to (that instead of a proportion of agents being the destabilising factor in the RA model, while the whole population causes instability with RD) suggests that there is still work to be done analysing the RA model. The question of how extremism may spontaneously appear without the need for already present extremism is one of the key factors that the RA model has been unable to answer. The RD model offers one possible, and very plausible explanation based on empirical evidence. Also, showing how highly clustered populations may still result in a single extreme convergence, something that clearly has happened in the real world, implies that the improvements of the RD model are worth further research.

It is prudent, therefore, to state that although the RD model offers a number of realistic and useful improvements over the RA model, both models represent useful tools to further learn about the dynamic of opinion spread.

Before any further work should be undertaken it is important to validate the findings and dynamics of both the RA and RD models. As has been discussed in the previous section, there are many disparate fields that are pursuing very similar lines of research apparently oblivious to other work that may be of use. For that reason, highlighting further applicability of these models, as well as looking for further validation of the models themselves, is an essential step in the development of our understanding of these dynamics.

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WEIGHTED ATTACK TREES FOR THE CYBERSECURITY ANALYSIS OF SCADA SYSTEMS

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ABSTRACT
In this paper we address the issue of security of SCADA systems; a topic of paramount importance because of the impact on physical security and very challenging because of the peculiarities that set SCADA systems aside from usual ICT networks. We apply the modeling technique based on structures called weighted Attack and Defense Trees (ADT) to a complex case study based on a typical SCADA architecture, in which the attack tree is enriched with the cost and the impact of the attack. We introduce a new analysis technique for weighted ADT based on the representation of the attack scenario by means of Multi-Terminal Binary Decision Diagrams (MTBDD) that allow the modeler to identify the most probable attack scenarios, in term of probability cost and impact, and gives an indication on how to mitigate the located breaches by means of suitable countermeasures.

1. INTRODUCTION

SCADA systems were developed as closed proprietary systems running in controlled and isolated environments. In the past decades they have gradually opened up to the world to take advantage of the new communication technology that allows remote administration and monitoring. This means that network security problems from the business network and the world at large could be passed onto process and SCADA networks, putting industrial production, environment integrity and human safety at risk (Stamp et al. 2003, Shaw 2012).

Since SCADA systems directly control physical systems, availability and reliability come first, whereas in ICT networks a significant stress is on confidentiality of information. Protection in an industrial control network must be achieved in a resource constrained environment, in which channel bandwidth is very narrow and devices have a limited computational power, whereas in contrast timeliness of response is fundamental. Since resources are bounded and at the same time delays are unacceptable, many security measures that work well in ICT networks cannot be used as is in SCADA networks: cryptography, especially public-key (Fuloria et al. 2010), is often too heavy, both computationally and because of the traffic it creates (American Gas Association 2006), and additional programs like antiviruses risk slowing down systems exceedingly (Kim 2012). Being born as isolated systems, they carry the burden of a legacy of trust in the network and thus they lack the tools for monitoring and self-protection that have long been integrated in ICT networks. For instance, their logging capabilities are geared towards disturbances rather than security attacks (Ahmedi et al. 2012).

Contrary to ICT network devices, SCADA systems are designed to run for years on end (Byres et al. 2006) without a reboot. This complicates the application of software patches and makes even forensics after an attack problematic because the system cannot be taken down and analyzed at wish (Ahmedi et al. 2012). Therefore the security analysis of SCADA systems requires specific tools and specific effort. We stress the need of activating in this field formal qualitative and quantitative evaluation techniques (Ortalo et al. 1999) that can support in the choice and implementation of the most effective protection mechanisms.

1.1 Methodology and related work

Attack trees (ATs) provide a formal, methodological way of describing the security of systems, and have gained acceptance both in industrial and academic environments. The notion of AT is due to Schneier (1999) who introduced them as a visual and systematic methodology for security assessment. An AT is a multi-level hierarchical structure based on logical AND and OR operators (Ten et al. 2007b). The leaves of the tree represent atomic attack exploits. The root node (or top event) is the ultimate goal, whereas internal gates represent intermediate subgoals. There is no standard way to represent ATs (for possible notations, cf. Byres et al. 2003, Ten et al. 2007a, Kordy et al. 2012); we use the notation of Fault Tree

Analysis as in IEC-10125 (1990).

Attack exploits can be considered as Boolean events (present or non-present), whose values propagate up the tree structure to determine which combinations of attack events lead to the final goal. Borrowing the terminology from Fault Tree Analysis, we can identify the list of the minimal combinations of elementary attack exploits that lead to the final goal as the minimal cut sets *(mcs)* of the AT.

Attack exploits can have different probabilities of success, different costs for the attacker, different impacts on the system if successful, thus leading to strategies of attack more or less rewarding for the attacker. These parameters must be then taken into account in a risk assessment, leading to the design of a defense strategy. In order to model these aspect, ATs are enriched by labeling each leaf with the probability of success of the corresponding exploit, the costs for the attacker and the impact of the atomic attack step. AT enriched with cost attributes are called weighted ATs (Bobbio et al. 2013).

In planning a defense strategy, one must evaluate possible countermeasures in the face of attack exploits. In order to do this, Attack and Defense Trees (Roy et al. 2011, Kordy et al. 2012), to which we refer in the following as ADT, incorporate leaves that represent defense mechanisms or countermeasures (Ten et al. 2007a) that hinder or mitigate with an assigned probability the effect of an attack exploit. The methodology of ADTs has been applied to SCADA systems (Byres et al. 2004, Ten et al. 2007a, Roy et al. 2011) with the aim of quantifying the risk of an attack and the feasibility of a defense strategy. This paper introduces a new representation and analysis technique for weighted ADTs based on an extension of Binary Decision Diagram (BDD), called Multi-Terminal Binary Decision Diagrams (MTBDD). MTBDDs provide a more general and efficient evaluation tool for the weight functions associated to an ADT and allow the modeler to evaluate the probability distribution function of the cost and impact related to any possible attack scenario. A case study of a typical SCADA architecture illustrates the methodology.

2. ATTACK ANALYSIS OF A SCADA CASE STUDY

We assume as a case study a typical SCADA architecture (Shaw 2012) as the one shown in Figure 1. With reference to Figure 1, the characterizing elements are the following. The SCADA control center (SCC) and the Human Machine Interface (HMI) have a complete redundant backup. The primary LAN connects the SCC to different services and facilities like a Web Server and the central Data Base. The SCC is connected to the Remote Terminal Units (RTUs) by means of a Master Terminal Unit (MTU) via a network that in our specific case is composed by a proprietary WAN with a backup connection through a public Telco network as detailed in Ciancamerla et al. (2010).

On the basis of the suggestions and analysis provided in

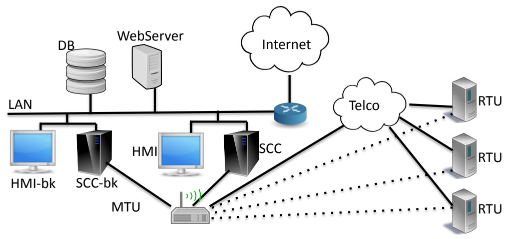


Figure 1: Typical SCADA architecture

Byres et al. (2004), Ten et al. (2007a), Roy et al. (2011), we investigate an attack scenario that assumes the event *SCADA compromised* as final attack goal (the top event of the AT). The attack may penetrate along three main lines:

- The first targets the RTUs (we assume three RTUs in our SCADA system), the MTU and the network that connects the RTUs to the MTU. We assume as basic attack exploits the compromise of an RTU, of the MTU or of one of the two network connections (atomic exploits $E01 - E06$ in Figure 2).
- The second line of attack is through the control center, composed by two blocks: the primary SCC and HMI, and their backups and the switch to commute between primary and backup (atomic exploits $E07 - E11$ in Figure 2).
- The third line of attack targets the central LAN in Figure 1 and the equipment and facilities connected to the LAN, like the hystorian Data Base, and the Web Server to the customers (exploits $E12 - E15$ in Figure 2).

With the above organization, the AT of Figure 2 represents an attack with 15 atomic exploits (leaves $E1 - E15$), 8 intermediate goals (gates $G2 - G9$) and one final goal (the top event, Gate $G1$). Table 1 reports the complete list of the basic attack exploits. If we assume that the time span before an attack exploit is delivered is an exponentially distributed random variable with known rate we can compute the probability vs time of successfully reaching the final goal Gate $G1$ as well as any intermediate gate. The computation can be performed by representing the Boolean structure of the AT by means of a Binary Decision Diagram (BDD) (Rauzy 1993) and computing the probability of reaching any level of the AT on the BDD. A BDD is a binary tree that terminates with two leaves 1 and 0 representing the combination of basic exploits that make the attack successful or non successful, respectively.

Using the attack rates reported in the third column of Table 1, the probability of reaching gate $G1$ vs time is reported in the graph a) of Figure 4.

The basic exploits do not have the same effect in determining the success of an attack, but their importance depends both on their probability and their position in the

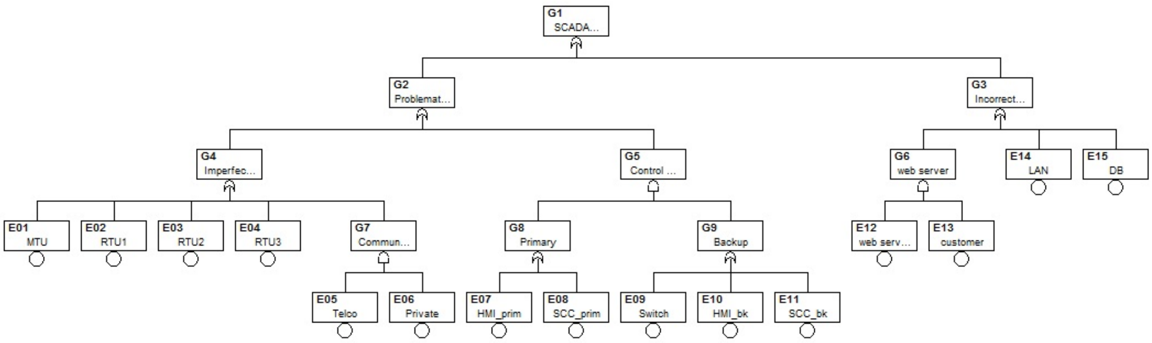


Figure 2: AT of the SCADA architecture

AT. A common indicator utilized to rank the importance of the basic exploits is the Birnbaum importance measure (Birnbaum 1969). It is defined as:

$$I^B_{x_i} = P(G_1(x_i = 1)) - P(G_1(x_i = 0)) \qquad (1)$$

where:

$P(G_1(x_i = 1))$ is the probability of the top event of the tree G_1 when leaf x_i is stuck to 1;

$P(G_1(x_i = 0))$ is the probability of the top event of the tree G_1 when the leaf x_i is stuck to 0.

The Birnbaum importance measure of an attack event represents the change in the probability that the final goal is reached caused by the probability difference when the attack exploit is used $(x_i = 1)$ or not $(x_i = 0)$. Table 1 reports the Birnbaum importance measures in Column 6 (computed at a mission time $T_M = 1800\ h$), and shows that, with the given attack rates, the RTUs turn out to be the most critical elements.

3. WEIGHTED ATS: COST AND IMPACT

A more effective and informative analysis of an attack sequence could be obtained by weighting the AT with specific attributes that have an influence on the attainment of an attack goal and may be therefore relevant to build a defense strategy (Roy et al. 2011). We identify two attributes: the cost of implementing a single atomic attack exploit and the monetary damage related to the implementation of an attack exploit. Propagating these values along the AT up to the final goal, we can evaluate the cost of attaining a successful goal attack, that we call *cost* of the attack, and the monetary damage caused by a successful attack that we call the *impact* of the attack.

Previous work (Roy et al. 2011) was devoted to derive the minimum value of the cost and the maximum value of the impact. Since in a probabilistic AT both the *cost* and the *impact* of the attack are discrete random variables, we propose in this paper to enlarge the view and to evaluate their distribution, i.e. to find which is the probability of reaching a successful attack at a given cost and with a given impact (Bobbio and Terruggia 2009).

A weighted AT is an AT whose basic (or intermediate) events are labeled with a variable representing some specific attribute of the events: in this case cost or impact. A weighted AT can be expressed and analysed by resorting to extensions of BDDs called Multi-Terminal Binary Decision Diagrams (MTBDDs), that, as extensions, inherit properties and algorithms from BDDs for regular ATs. An MTBDD (Clarke et al. 1995) is like an ordinary BDD except that the terminal leaves can be arbitrary real values instead of just 0 and 1 and can be used to represent all the possible values taken by the weight function in any possible attack scenario. To weight the AT of Figure 1, we have assumed for the atomic attack exploits $E1 - E15$ the cost and the impact values reported in the fourth and fifth columns of Table 1, respectively. The value at the terminal leaves of the MTBDD is the value of the total cost (or impact) accumulated in any possible attack scenario, obtained by propagating the cost (or the impact) of the basic attack exploits along the AT up to the top goal, with the following rules (Bobbio and Terruggia 2009, Roy et al. 2011):

1. the *cost* (resp. *impact*) in output to an AND gate is the sum of the costs (resp. impacts) of its inputs elements. The rationale behind this propagation rule is that all the inputs must be true for an AND gate to be true and hence their costs sum up.

2. the *cost* in output to an OR gate is the minimum cost among its inputs while the *impact* in output to an OR gate is, on the contrary, the maximum impact among its inputs. The rationale behind this propagation rule is that in front of a choice represented by an OR gate, the most convenient strategy for the attacker and the worst scenario for the defender is the alternative with the minimum cost and the maximum impact.

The results obtained from the analysis of the MTBDD, computed at a mission time $T_M = 1800\ h$ (corresponding to 75 days), are shown in Table 2. Column 1 reports the values that the total cost c can assume in any possible scenario. Column 2 is the probability mass of reaching a successful attack goal with the corresponding cost c; the last row labeled $n.s.$ is the probability that

Table 1: Target of the exploit, attack rate, cost, impact and Birnbaum index for the attack leaves of Figure 2

leaf	*target of the exploit*	*attack rate*	*cost*	*impact*	*Birnbaum index*
$E01$	*MTU*	1.00E-04	275	175	0.1930
$E02$	*RTU*	2.00E-04	300	350	0.2311
$E03$	*RTU*	2.00E-04	300	350	0.2311
$E04$	*RTU*	2.00E-04	300	350	0.2311
$E05$	*TELCO*	5.00E-04	200	30	0.0140
$E06$	*Private WAN*	5.00E-05	20	100	0.0140
$E07$	*HMI Primary*	5.00E-04	100	50	0.0274
$E08$	*SCC Primary*	1.00E-04	150	150	0.0133
$E09$	*Switch to Backup system*	1.00E-03	200	50	0.1084
$E10$	*HMI backup*	5.00E-05	100	50	0.1084
$E11$	*SCC Backup*	1.00E-05	150	150	0.1009
$E12$	*Web Server vulnerabilities*	3.00E-04	50	75	0.0285
$E13$	*Customers*	1.00E-04	175	10	0.0722
$E14$	*LAN*	1.00E-04	175	50	0.1930
$E15$	*DB Data Base*	1.00E-04	250	400	0.1930

Table 2: Probability of successful attacks as a function of cost with mission time $T_M = 1800\,h$

cost	*probability of successful attack*	
c	*of cost c*	*of cost* $\leq c$
200	0.051076	0.051076
225	0.065223	0.116299
250	0.157582	0.273881
275	0.219523	0.493404
300	0.343209	0.836613
350	0.000954	0.837567
375	0.001203	0.838770
$n.s.$	0.161230	-

Table 3: Probability of successful attacks as a function of impact with mission time $T_M = 1800\,h$

impact	*probability of successful attack of*	
i	*impact i*	*impact* $> i$
$n.s.$	0.161230	
80	0.001203	0.837567
85	0.011989	0.825578
100	0.015871	0.809707
175	0.082459	0.727248
200	0.010068	0.717180
300	0.123749	0.593431
350	0.428701	0.164730
400	0.164730	0.0

the attack is not successful by time T_M. Column 3 is the cumulative distribution function i.e. the probability that an attack is successful with a cost $\leq c$. Note that the cumulative distribution is defective, since there is a non null probability that the attack is not successful. In Table 3, Column 1 reports the possible impacts *i*, Column 2 the corresponding probability mass and Column 3 the survivor distribution function i.e. the probability that an attack is successful with an impact $> i$. Note that the survivor distribution is defective at the origin with a mass equal to the probability that the attack is non successful (row $n.s.$).

Additionally, from the MTBDD we can obtain more detailed indications on the most dangerous attack strategy by listing all the possible *mcs* with their probabilities of occurrence, costs and impacts as in the left part of Table 4. The *mcs* are listed according to their occurrence probability, i.e. the first in the list is the most probable. But if we rank the *mcs* according to their cost or impact we get a different order. The attack strategy mcs_4 consisting in compromising the MTU turns out to have a rather high probability coupled with high impact and somewhat low cost.

4. ATTACK AND DEFENSE TREE (ADT) FOR SCADA SYSTEM

The analysis carried on in the previous section gives the rationale to implement effective defense strategies, by activating countermeasures that can hinder an attack exploit: either preventing it altogether or reducing its probability of sucess (Ten et al. 2007a, Roy et al. 2011). Logically, an exploit can be successful only if the countermeasures designed to counter it fail. Therefore countermeasures appear in an AT as *negated* inputs to an AND gate whose other inputs are the events that the countermeasures should inhibit (Roy et al. 2011). In order to avoid cumbersome notation, we let countermeasure leaves denote *negated countermeasures* and omit the explicit negation altogether. Consequently, the probability attached to a countermeasure leaf is the probability of failure of the

Table 4: *MCS*, cost, impact and probability without (left part) and with (right part) countermeasures

	without countermeasures				with countermeasures	
mcs no.	*mcs elements*	*cost*	*impact*	*probability*	*mcs elements*	*probability*
1	E02	300	350	0.302324	E02 C02	0.009070
2	E03	300	300	0.302324	E03 C03	0.009070
3	E04	300	350	0.302324	E04 C04	0.009070
4	E01	250	400	0.164730	E01 C01	0.002471
5	E14	275	175	0.164730	E14 C14	0.003295
6	E15	275	175	0.164730	E15 C15	0.003295
7	E12 E13	225	85	0.068734	E12 C12 E13 C13	0.001031
8	E07 E09	300	100	0.051076	E07 C07.1 C07.2 E09	1.187e-4
9	E07 E10	200	100	0.051076	E07 C07.1 C07.2 E10 C10.1 C10.2	2.043e-3
10	E08 E09	350	200	0.014178	E08 C08 E09	4.942e-5
11	E08 E10	250	200	0.014178	E08 C08 E10 C10.1 C10.2	8.507e-4
12	E07 E11	250	200	0.010586	E07 C07.1 C07.2 E011 C0-11	4.234e-4
13	E05 E06	375	80	0.007408	E05 C05 E06 C06	2.043e-3
14	E08 E11	300	300	0.002939	E08 C08 E11 C11	1.763e-4

countermeasure.

The vulnerabilities of a SCADA system can be evidenced utilizing the methodology and tools offered by the US Department of Homeland Security by means of the Cyber Security Evaluation Tool (CSET 2011), that, additionally, offers the possibility of investigating the effect of various countermeasures. Inspired by CSET (2011) and by (Ten et al. 2007a) we apply to each atomic exploit one or more countermeasures as listed in Table 5, whose probabilities of failure are reported in the last column.

We avoid resorting to cryptographic countermeasures, in view of the delay they impose on the systems, as discussed in the Introduction. On the other hand, we use digital certificates on the Web Server that has no strict timeliness requirements. To enhance reliability and availability of the system, it is very important that only authorized personnel can operate on the system, and that traffic from public networks be accurately monitored. Therefore we focus on secure identification of operators (eliminating guest accounts and default passwords, and implementing biometric authentication and password ageing). Moreover we filter traffic from public newtorks using Intrusion Detection/Prevention Systems (IDS/IPS). In particular we dedicate a more structured protection (that we denote generically "firewall") to RTUs since the analysis on the AT has revealed that they are critical elements (cf. Table 1). Finally, we choose to implement a perimetral network, commonly known as DMZ from Demilitarized Zone, between the corporate network and the control network (following Stouffer et al. 2011, Sect. 5.3.4). On the DMZ we place components that must be accessible from both networks (in our case the Data Base).

To visualize the application of the countermeasures, we have reported in Figure 3 the portion of the total AT of Figure 2, rooted at gate *G*5. By proceeding as in the previous section, from the ADT with all the countermeasures listed in Table 5 we can build the related MTBDD,

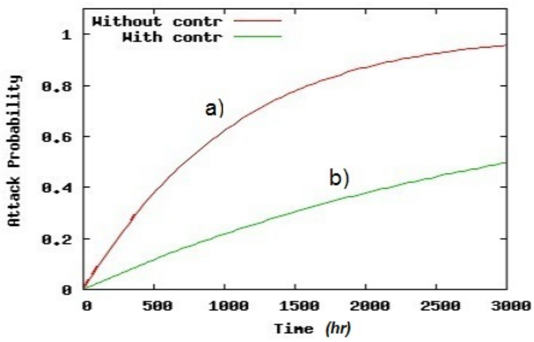


Figure 4: Comparison of attack probability vs time (in *h*) with and without countermeasures

and from the MTBDD we can evaluate the probability of reaching the final goal vs time, and the probability distributions of the cost and the impact in case of a successful attack. Figure 4 compares the probabilities of achieving the ultimate goal computed for the AT (graph a) and for the ADT (graph b) and enlightens the mitigation effect due to the application of the countermeasures. Further, in Tables 6 and 7, we report the mass probabilities, the distribution for the cost and the survivor function for the impact. The difference in the distributions with and without countermeasures taken from Tables 2 and 6 (resp. Tables 3 and 7) is evidenced in Figure 5 (resp. Figure 6), showing how the introduction of the countermeasures reduces the probability that an attacker reaches the final goal investing the same budget. A refinement and a review of the implemented security plan goes through the analysis of the attack strategies that emerge from the examination of the singular *mcs* of the ADT. To this end, we have compared in Table 4 the composition of the 14 *mcs* with and without countermeasures, by reporting the probability of occurrence of each *mcs* in the two cases.

Table 5: Attack exploits from Table 1 with the implemented countermeasures and the related probability of failure

leaf	*Attack target*	*Counter measure*	*Countermeasure description*	*Failure Probability*
*E*01	*MTU*	*C*01	*IDS/IPS*	0.15
*E*02	*RTU*	*C*02	*Firewall*	0.3
*E*03	*RTU*	*C*03	*Firewall*	0.3
*E*04	*RTU*	*C*04	*Firewall*	0.3
*E*05	*TELCO*	*C*05	*IDS/IPS*	0.2
*E*06	*Private WAN*	*C*06	*IDS/IPS*	0.2
*E*07	*HMI Primary*	*C*07.1	*Eliminate Guest Account*	0.5
		*C*07.2	*Implement Password Age*	0.4
*E*08	*SCC Primary*	*C*08	*Eliminate Factory Default Password*	0.3
*E*09	*Switch Backup system*	-		
*E*10	*HMI backup*	*C*10.1	*Eliminate Guest Account*	0.5
		*C*10.2	*Implement Password Age*	0.4
*E*11	*SCC Backup*	*C*11	*Eliminate Factory Default Password*	0.3
*E*12	*Web Server vulner*	*C*12	*Implement Digital Certificates*	0.5
*E*13	*Customers*	*C*13	*Implement Biometric Authetication*	0.3
*E*14	*LAN*	*C*14	*IDS/IPS*	0.2
*E*15	*DB Data Base*	*C*15	*DMZ (Demilitarized Zone)*	0.2

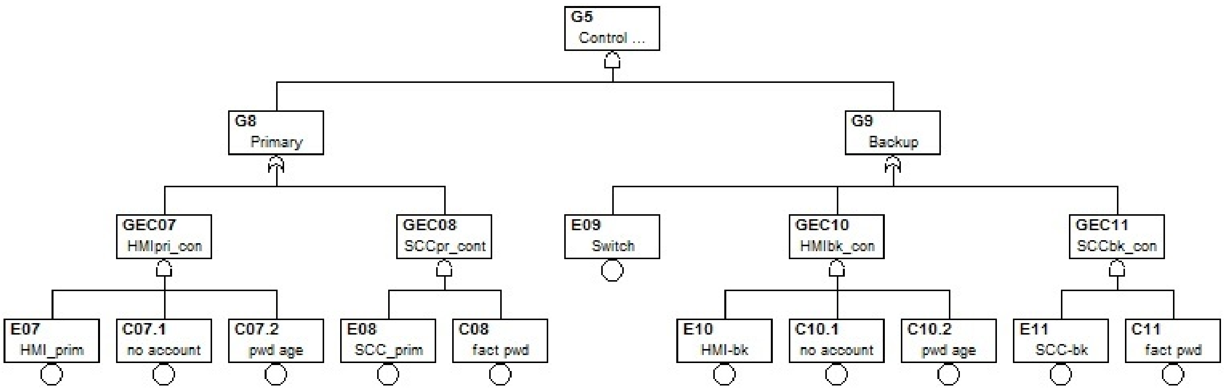


Figure 3: Subtree with countermeasures rooted at Gate *G5*

Observe how the rank of the *mcs* with repsect to their occurrence probability is modified passing from the AT (left part of Table 4) to the ADT (right part of Table 4).

The data of Table 4 are graphically reported in Figure 7 in a logarithmic scale. The most dangerous attack strategies are those in the upper left corner of Figure 7a (low cost and high probability of success), and in the upper right corner of Figure 7b (high impact and high probability of success). The probabilities and costs (resp. impacts) of attack strategies in absence of countermeasures are marked with red crosses, those in presence of countermeasures are marked with green circles. These figures give an evaluation at-a-glance of the security plan implemented: the plan is acceptable if there are no green circles in the upper left corner of Figure 7a and in the upper right corner of Figure 7b. The security plan we implemented turns out to be rather good, but Figure 7a shows that it can be further improved.

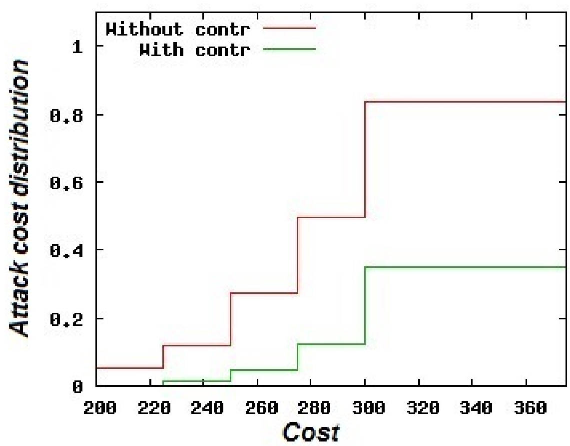
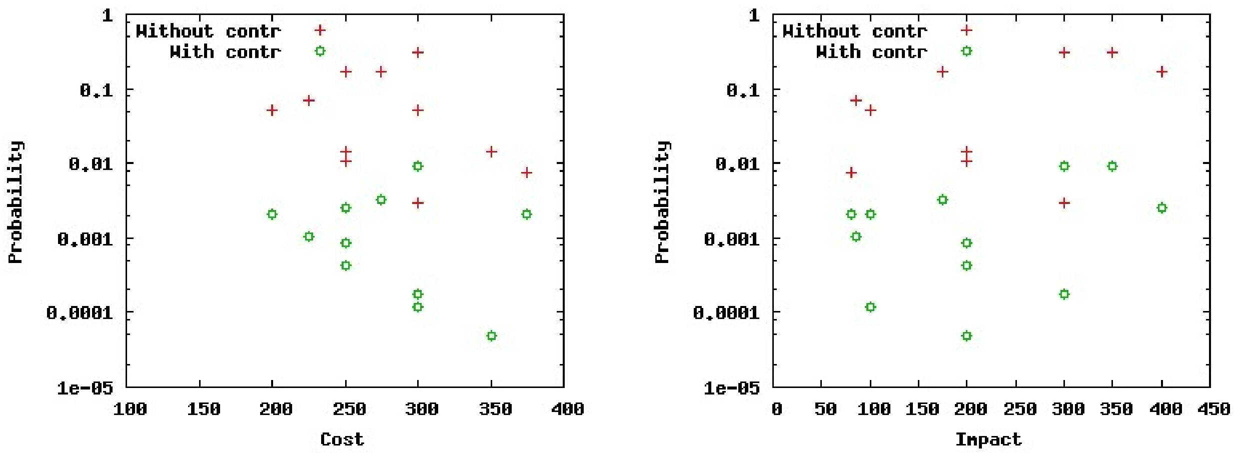


Figure 5: Distribution of cost with and without countermeasures



a) b)

Figure 7: Comparison of *mcs* probability for AT and ADT vs cost a) and impact b)

Table 6: Probability of successful attacks as function of cost for the ADT for the SCADA system with mission time $T_M = 1800\,h$

cost	*probability of successful attack*	
c	*of cost c*	*of cost* $\leq c$
n.s.	0.649845	-
200	0.002043	0.002043
225	0.010289	0.012332
250	0.033855	0.046187
275	0.077008	0.123195
300	0.224344	0.347539
350	0.002424	0.349963
375	0.000193	0.350155

Table 7: Probability of successful attacks as functions of impact for the ADT for the SCADA system with mission time $T_M = 1800\,h$

impact	*probability of successful attack of*	
i	*impact i*	*impact* $> i$
80	0.000193	0.349962
85	0.006772	0.343191
100	0.007635	0.335555
175	0.058357	0.277199
200	0.004077	0.273121
300	0.072713	0.200409
350	0.167463	0.032946
400	0.032946	0.0
n.s.	0.649845	-

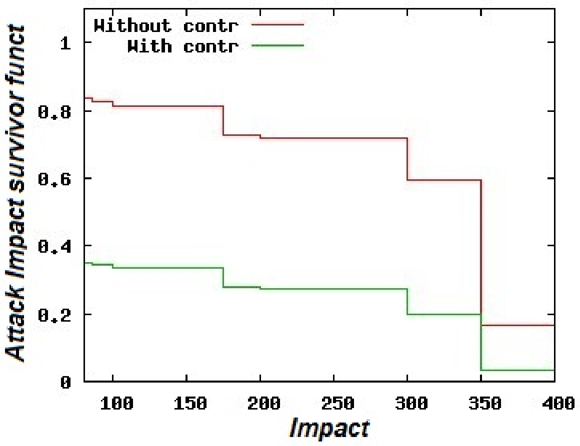


Figure 6: Distribution of impact with and without countermeasures

5. CONCLUSIONS

SCADA systems are highly critical systems and their cyber-security has its own peculiarities with respect to standard ICT systems, so that the study of the possible attacks to SCADA systems requires specific formal modeling and analysis tools able to provide qualitative and quantitative evaluations. We have investigated, in details, the modeling tool based on Attack and Defense Trees (ADTs). Standard ADTs are based on Boolean logic, and their qualitative and probabilistic properties can be analyzed by resorting to BDDs. However, if the analysis is enriched with a parametrization of the cost and the impact of the attack, the binary representation is not sufficient and we should resort to a more effective analysis technique. We have shown in this paper that the extension of the BDD called MTBDD provides an effective technique to represent and solve weighted ADT. Future work is oriented to include in the analysis the cost of implementing the countermeasures and to investigate how the budget of an attacker must be incremented in presence of countermeasures.

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MODELLING INTRUSION DETECTION IN SECURITY SYSTEMS

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ABSTRACT

With the ever increasing wireless connectivity and complexity of infrastructure-oriented systems, security is a very important issue for all network-based infrastructures in a modern enterprise environment. There are many examples of intruders and attackers who made successful attempts to seriously affect assets of high-profile organisations and companies. In some cases, the entire infrastructure of a company was brought down, resulting in a prolonged disablement of business, provided services, loss of money and reputation. Many methods, techniques and tools have been developed to secure the assets, network infrastructure and communication of various organisations. Intrusion detection is a relatively new addition to such methods, hence the tools that use advanced intrusion detection techniques started to appear only recently. Using intrusion detection methods, we are able to collect and use information from known types of attacks and find out if someone is trying or even attempting to penetrate our infrastructure or attack our assets. The information collected and accumulated in this way can then be used to harden the infrastructure/network security of the organisation/enterprise and possibly can be used for legal cases. This paper aims to present various issues related to security services, describes methods, techniques used in intrusion detection that can be useful when building and designing effective security systems.

Keywords: modelling methodology, intrusion detection, security system, decision support system

I. INTRODUCTION

There are two main methods of intrusion detection based on the approach to event analysis, signature-based detection and anomaly based detection. Brief descriptions of their functionalities are explained, along with supporting advantages and disadvantages in the subsequent sub-sections.

1.1. Signature-based Detection

This methodology is similar to the way many anti-virus programs incorporate virus signatures to recognise and restrict access to infected files, programs, or active web content from entering a computer system. The attack signatures in this case are comprised of network traffic and activity patterns relating to known attacks. Signature detection is the most widely used approach in commercial intrusion detection systems.

1.1.1. Disadvantages

Signature-based detection scrutinizes ongoing traffic, user activity or transactions, and behaviours looking for matches with known patterns of events specific to known attacks. This intrusion detection system requires access to a current database of attack signatures, and is able to actively compare and match current behaviour against the large collection of signatures. This technique works extremely well for categorised and previously known attacks. Signature databases will require constant updates to be more reliable. Contrary to this, if signature definitions are too specific, this will induce another disadvantage in missing variations of known attacks. This technique is similar to the approach taken to modify polymorphic viruses, where hackers in this case, create new attacks by changing steps in existing known attacks rather than creating entirely new ones. In addition, signature-based detection causes bottlenecks in performance, when current behaviour matches multiple or numerous attack signatures, either in whole or in part.

1.2. Anomaly-based Detection

This methodology operates in a similar fashion as anti-virus heuristics checking, but in this case it uses rules or predefined concepts about "normal" and "abnormal" system activity. These rules can also be referred to as heuristics, and can distinguish anomalies from normal system behaviour. They monitor report on, or block anomalies as they occur. Some intrusion detection systems only support limited types of anomaly detection. Most experts 0, 0 believe this type of detection methodology will become more popular as artificial intelligence becomes more prominent 0, 0, 0 Anomaly based detection examines ongoing traffic, user activity or transactions, and behaviour looking for anomalies on networks or systems that may indicate attack. Based on the premise that "attack behaviour" differs considerably from "normal user behaviour", detection of intrusions can be carried out by cataloguing and identifying the differences involved. This makes it possible to create baselines of normal behaviour, and allow the anomaly based IDS to observe when current behaviour deviates statistically from the norm. The advantage of this, in theory, provides anomaly based intrusion detection systems the ability to detect new attacks for which signatures are yet to be established.

1.2.1. Disadvantages

A major drawback to anomaly based detection stems from the fact that normal behaviour is dynamic and changes readily and easily. This method of detection is prone to false positives – where attacks may be reported based on simple changes to the norm rather than representing real threats. Another disadvantage is that the intense analytical characteristics of this methodology often impose extreme processing overheads for systems they are running on. In addition, anomaly based systems require considerable time to create statistically sounding baselines; during this period they are vulnerable to intrusion.

2. PHYSICAL SECURITY DISRUPTION

The purpose of this paper is to demonstrate the versatility of adapting both probabilistic and evolutionary (biomimetic) paradigms in development of security services within a software system infrastructure. There is an extensive literature that covers various aspects of biomimetic computational models such as Genetic Algorithms (GA) and Artificial Immune System (AIS) and their applications 0, 0, 0, [8]. To validate the models and understand its limitations we have built a middleware security system framework with genetic and immune-computing paradigms. It is anticipated the applicability of the biomimetic paradigms becomes evident in the experiment 0.

3. A VIRUS ATTACK SCENARIO

A new unknown virus enters the software system and its undesirable presence or activities have been detected. The source(s) of the virus spread (carrier files) has to be located first. After performing some virus containment activities - a security expert has to distribute the code in order to detect the signature (pattern) which could help into provide a unique identification of the software virus. Consecutively, to heal (patch) infected networks, subsystems or files an effective antivirus can be developed. The signature of the virus is then be stored in a data-store (database), to allow specialised antiviral programs to detect and prevent known viruses from attacking the computer networks. Finally, data consistency and integrity on the system has to be verified, and further precautions, if required are taken. A similar procedure process has been repeated for all new variants of the virus (strains).

4. PROPOSED SOLUTION

Currently, there are several biomimetic metaphors being actively investigated by researchers in the engineering and informatics communities. Among the most popular bio-inspired models that are being adopted for a new generation of security systems are: protein pathway mapping, neural feedback loops and gene behaviour 0, 0. Our research focuses on constructing the architectural framework of the ISS that draws on maturity of de-facto security industry standard EASI (Estimation of Adversary Sequence Interruption) model 0 and taking an advantage of biomimetic methodologies. The architectural model of the proposed Biomimetic Security System (BISS) extends the EASI model by incorporating a set of biomimetic concepts and algorithms operating within a dedicated software infrastructure. The design of an Intrusion Detection services component in the BISS software infrastructure attempts to exploit the best aspects of probabilistic and evolutionary techniques. The architectural driver requirements for the proposed BISS have to ensure: autonomics (self-organisation and adaptation), interoperability, distributiveness and its lightweight footprint. By design, the various network components (nodes) are required to assess the situation, cooperate to defend and pool available resources and assist in decision making by adopting genetic and immune-computing principles.

5. EASI MODEL

Garcia's Estimation of Adversary Sequence Interruption (EASI) framework 0 is based on a probabilistic model that describes all elements of the system security system in terms of their safety and possibility of improvement. These aspects are expressed in probability estimates for item failure and possibility of security interruptions. The analytical work, including adjustment of various parameters, is still largely based on human intuition and experience. This is in order to obtain a meaningful interpretation of the results. The element of the security system, pertinent to EASI model includes physical properties and probabilities. Among physical properties are: adversaries (the opponent and his/her skill level), sensors and actuators (cameras, microwave, IR, fence sensors, switches and other devices), barriers (doors, walls, screens, etc.) located at points along the adversary path, communication devices, response force (the guards or other teams that protect the facility), the protected assets, path(s) taken by an adversary to reach the asset, points along the path and other elements. The calculation of probabilities involves the following parameters:

- $P(D)$, Probability of detection (associated with each sensor).
- $P(A)$, Probability of the alarm.
- $P(C)$, Probability that communications (in the facility) will be available.
- $P(I)$, Probability of interrupting the adversary along his or her path.
- $P(\frac{R}{A})$, given an alarm has sounded, the probability (conditional) that the response force will arrive.
- t_i, time that a barrier at a given point might be disrupted. The time value is dependent on the

adversary's skill level and tools possessed. This time can be thought of as the time the adversary takes to complete a task, such as breaking through a fence.

- RTF, the time a response force might take to respond to a given threat.
- TR, the time remaining for the adversary to reach the end point (the asset) once an alarm sounds.

The model uses the following equations:

$$P(A) = P(D)P(C) \text{ and } P(\tfrac{R}{A}) = \int_0^{\infty} \frac{1}{\sqrt{2\pi\sigma_x^2}} e^{-[\frac{(x-\mu_x)^2}{2\sigma_x^2}]dx} \quad [1]$$

and where the mean is defined as:

$$\mu_x = E(TR) - E(RFT) \quad [2]$$

and variance:

$$\sigma_x^2 = Var(TR) + Var(RFT) \quad [3]$$

In practice, the tables are to store calculations of the mean and variance values. These tables show the times it may take an adversary with different set of tools to penetrate a barrier. The terms in the mean ux are:

$$E(TR)_p = E\left(t_{AD_p}\right) + \sum_{i=p+1}(t_i) \quad [4]$$

Where $E(TR)p$ is the expected time from any point p to the end point (the asset) n; the $tADp$ is the time after the detection (the intrusion was detected) at the point p; and the $E(t_i)$ value is the expected time to perform a task at a given time i along the intrusion path.

$$E\left(t_{AD_p}\right) = \begin{cases} E(t_i) & \text{if detection is at beginning} \\ \frac{E(t_i)}{2} & \text{if detection is in the middle} \\ 0 & \text{if detection is at the end} \end{cases} \quad [5]$$

The TR and RFT are independent and normally distributed. The normal distribution is approximated by letting both TR and RFT be sums of random variable which satisfy the conditions of the Central Limit Theorem. Thus, the final equation that calculates the probability of the interrupting the intruder given all definitions of probabilities above is:

$$P(I) = P(D_1)P(C_1)P(R|A_1) + \prod_{i=2}^{n}[P(D_i)P(C_i)P(R|A_i)\prod_{j=1}^{i-1}(1-P(D)_j)] \quad [6]$$

The below table shows probabilities of detection $P(D)$ for selected sensors as the adversary can cut, crawls, walks, run, cuts the wire or break the sensor that we used in experiments. These probabilities values give an indication of the level of efficiency of the sensors in detecting an adversary. Currently, the data is empirical, depending on the research data-set used as a reference. The second table indicates probabilities of intrusion detection when adversary actually attempts to defeat various sensors when performing different modes of movements/activities as indicated in Table 1. On the other hand, Table 2 indicates probabilities of intrusion detection when adversary actually attempts to defeat the sensors. Table 3 below indicates action (penetration) times for an intruder travelling on foot, carrying explosives and metal cutting tools. The action time would vary depending on the intruder's skill level, weight carried, prior knowledge of the surround and possible inside support. Penetration time is also called a delay time, as the barriers *pr* action causes delays to the adversary.

Table 1: Probabilities of Intrusion Detection in Intrusion Modes

Sensor	Slow Walk	Run	Crawl	Cutting
Continuity	-	-	-	0.75
Light Beam	0.9	0.9	0.75	-
Mechanical Switch	0.9	0.9	-	-
PIR	0.75	0.75	0.5	-
Microwave	0.75	0.75	0.5	-
Press. S/W	0.75	0.75	0.75	0.75
Strain	0.75	0.75	0.75	0.25
Light level	0.25	0.25	0.25	0.25
CCTV	0.9	0.9	0.9	?

Table 2: Probabilities of Intrusion Detection for Various Locations of Sensors

Sensor	$P(D)$
Combined badge reader	0.75 – 0.85
Officer at a check-point	0.5
Detectors on all walls	0.85 – 0.99
Exterior microwave detector	0.75 – 0.95

Table 3: Penetration Times for Various Actions of an Intruder.

Action	Slow walk	Run
Climb gate/fence	10s	±30% of expected *t*
Doors	12s	"
Badge reader station	8s (if all correct biometrics possessed)	"
Getting pass a checkpoint officer	30s	"
Door 6in metal	60s	"
30cm reinforced concrete walls/floors	3min	"
Door 3in metal	30s	"
1in interior wooden doors	60s	"

6. APPLICATION WITH SPRING TENSOR MODEL

The EASI method to determine the task probability of penetration and interruption activities can be alternatively applied by a globalized trajectory mapping method to analyse the magnitude and change of an intruder's movement.

The global trajectory method used in the experiment uses the Spring Tensor Model (STEM), a model that analyses protein fluctuation dynamics. As discussed in depth by Lin and Song 0, 0, the premise of the spring tensor model is to determine conformational changes in proteins using for calculating second-order partial derivatives (Hessian matrices) as indicated in Table 4. Conformational change is the transition of macro-molecular structures in proteins as a result in a change of acidity, temperature, voltages and so forth. The spring tensor model is an enhancement of anisotropic modelling and Gaussian modelling methods, as while the former determines fluctuations of an atom's direction, the latter is better at determining the prediction of magnitudes of direction 0. Thus by combining the two methodologies, the spring tensor model can be applied to the EASI method as follows:

6.1. Anisotropic Modeling

This modeling denotes the determination of conformational variation or fluctuation in direction between elements.

- ***Adaptation:*** This is suitable for determining how the interactions between an intruder and the asset will result in the degree of directional fluctuation. The variation of potential direction will indicate what possible directions an intruder will travel if they are in proximity with a security sensor, such as a motion detector.
- ***Meaning:*** Smaller anisotropic values indicate a smaller potential in which an intruder will move, while larger values indicate a larger potential for the intruder to move.

6.2. Gaussian Modelling:

This modeling is described n terms of determination of conformational variation or fluctuation in magnitude between elements.

- ***Adaptation:*** This is appropriate to ascertain how interactions between an intruder and a sensor will result in the magnitude or total range of the fluctuation. The variation of potential magnitude indicates the possible maximum range the intruder will travel if it is near the proximity of the sensor.
- ***Meaning:*** Smaller magnitudes values indicate a smaller potential of the intruder to alter their distance, while larger magnitudes indicate a larger potential for the intruder to alter their movements.

The STEM model's fourth term is of interest as it examines the global interactions of the elements. The final term, examined in Table 4, is shown with its Taylor expansion form [6]. The final non-local derivation is adopted from Lin and Song's calculations, which is used as a point of reference in this research project 0. Using the parameters stated by Clementi 0, the value of epsilon (ε) adopted is 0.36 as per conformation observations of macro-molecular protein structures using X-ray crystallography.

Table 4: Elaboration of the STEM Modelling Approach

$Y(X,Y_0) = \Sigma_{V1Bond} + \Sigma_{V2Angle} + \Sigma_{V3Dihederal} + \Sigma_{V4Non-Local}$	The $V(X,Y_0)$ values are sum of radial lengths, bonding angles and dihedral angles of consecutive objects i and j. Non-local contacts are used.
$V_4 = [5\left(\frac{r_0,ij}{r_{ij}}\right)^{12} - 6(\frac{r_0,ij}{r_{ij}})^{10}]$	The final non-local contact term is derived from the Go-like potential as discussed by Lin & Song's theoretical work.
$Y(X,Y_0) = \Sigma_{V1Bond} + \Sigma_{V2Angle} + \Sigma_{V3Dihederal} + \Sigma_{V4Non-Local}$	Taylor expansion of initial non-local contact term yields the equation, where r_{ij} and $r_{0,ij}$ are consecutive long-term values for objects i and j.
$\frac{\delta^2 V_4}{\delta X_i \delta Y_j} = \frac{240\varepsilon}{r_{0,ij}^2}(X_j - X_i)(Y_j - Y_i)^2$	As focus is on the equilibrium fluctuations, r_{ij} is equal or approximately equal to $r_{0,ij}$ at equilibrium; thus the derivative of V_4 can be simplified.

7. APPLYING THE METHODOLOGY

The proposed methodology is to be executing in several steps as follows:

STEP 1: In this step from site diagrams/maps we need to construct the possible adversary paths. The time to complete the task is called the Expected penetration time denoted as $E(t_i)$. Along the path, the adversary encounters different set of sensors which must be overcome in order to reach the asset. Associated with of the sensors is a Probability of detection $P(D)$ as indicated in the adversary path diagram for a selected site (Fig.1).

STEP 2: In this step all tasks are tabulated, and we use look-up tables to the allocated probabilities of detection $P(D)$ and expected barrier penetration times $E(ti)$. A standard deviation of ±30% is applied throughout the experiment. The values in Table 5 are determined using Tables 1, 2 and 3.

STEP 3: In this step we require to make the assumptions for the values of expected reaction time $E(RFT)$, the standard deviation $Var(RFT)$ and the probabilities for communication in the facility $P(C)$.

Research by Garcia 0 has indicated that appropriate values for $E(RFT) = 300s$, $Var(RFT) = 30s$ and the probabilities for communication in the facility $P(C) = 0.95$. This indicates the communication between security staff and all other parts of the facility are 0.95 probable. As follows, we need to calculate the values of Mean Variance parameters defined as:

$$\mu = E(TR) - E(RFT) \quad [7]$$

$$\sigma^2 - Var(TR) + Var(RFT) \quad [8]$$

and $P(\frac{R}{A})$, and finally the value of $P(I)$ using the previously defined formulas.

STEP 4: For each task indicated in the table defined in Step 2, locate tasks that have associate sensors in the neighbourhood. We need to decide if the adversary can be detected before the tasks begins, during the task or the completion of the task. If for example, we take task 6 as the adversary walks into the room, he or she can be detected by the PIR. In this case, the detection can occur before the task begins, such as crawling towards the next door. Hence, the following conditions can be considered (see Table 6):

- If detection occurs before a task begins, assign a $'B'$.
- If detection occurs in middle of task, assign an $'M'$.
- If detection occurs at end of task, assign an $'E'$.

STEP 5: In this step, the probability of interruption is calculated. The outputs of all the calculations used are presented in Table 8.

Thus the task probabilities for various penetration and interruption activities can be updated, with the optional application of the STEM model applied at this stage. Adjustments according to various detection conditions are established, due to deployment of various detectors and sensory systems as indicated in Table 7.

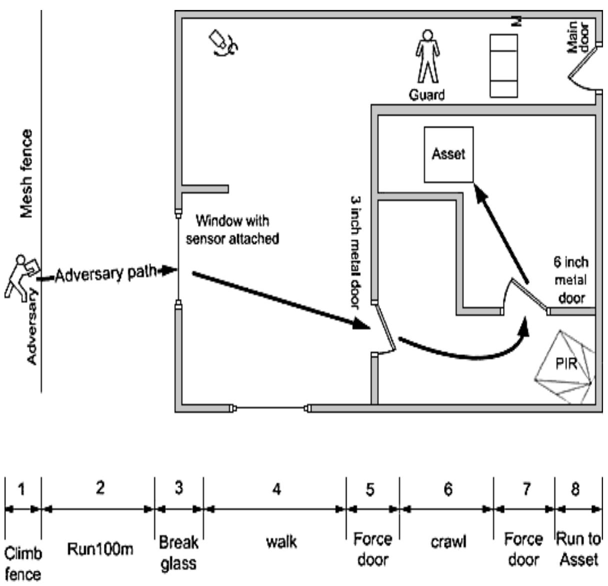

FIGURE 1: An adversary path for a given site.

Table 5: Allocated Probabilities and Expected Barrier Penetration Times for Listed Tasks.

Task	Description	Any Sensors	$P(D_i)$	$E(T_i)$ in sec	$Var(T_i)$ in sec
1	Climb fence	Fence Sensor	0.9	10s	3s
2	Run (100m)	None	0	60s	18s
3	Break Glass	Continuity Sensor	0.75	10s	3s
4	Walk	CCTV (PTZ)	0.9	10s	3s
5	Force Door (3in metal)	None	0	30s	9s
6	Crawl (10m)	PIR	0.5	20s	6s
7	Force Door (6in metal)	Pressure, Biometrics	0.9	60s	18s
8	Run to asset	No	0	5s	1.5s

Table 6: Conditions for $\boldsymbol{E(TR)}$ and $\boldsymbol{Var(TR)}$.

The Conditions for $E(TR)$	**The Conditions for $Var(TR)$**
If 'B' then $E(TR) = E(t_p) + \sum_{i=p+1}^{n} E(t_i)$	If 'B' then $Var(TR) = Var(t_p) + \sum_{i=p+1}^{n} Var(t_i)$
If 'M' then $E(TR) = \frac{E(t_p)}{2} + \sum_{i=p+1}^{n} E(t_i)$	If 'M' then $Var(TR) = \frac{Var(t_p)}{4} + \sum_{i=p+1}^{n} Var(t_i)$
If 'E' then $E(TR) = \sum_{i=p+1}^{n} E(t_i)$	If 'E' then $Var(TR) = \sum_{i=p+1}^{n} Var(t_i)$

Table 7: Adjusted Values for Probabilities and Barrier Penetration Times for Listed Tasks

Task	Description	Any Sensors	Det	$P(D_i)$	$E(T_i)$ in sec	$Var(T_i)$ in sec
1	Climb fence	Fence Sensor	B	0.9	10s	3s
2	Run (100m)	None	E	0	60s	18s
3	Break Glass	Continuity Sensor	B	0.75	10s	3s
4	Walk	CCTV (PTZ)	B	0.9	10s	3s
5	Force Door (3in metal)	None	E	0	30s	9s
6	Crawl (10m)	PIR	B	0.5	20s	6s
7	Force Door (6in metal)	Pressure, Biometrics	B	0.9	60s	18s
8	Run to asset	No	B	0	5s	1.5s

Table 8: Calculation of the Probability of Interruption $\boldsymbol{P(I)}$.

	Adversary	**Probability of Guard**		**Response Force Time (s)**	
	Sequence	**Communicate**		**Mean**	**Std Dev.**
	Interruption	**0.05**		**300**	**90**
				Delays (in secs)	
Task	**Description**	**P(Detection)**	*Loc*	**Mean**	**Std Dev.**
1	Climb fence	0.9	B	10	3
2	Run (100m)	0	B	60	18
3	Break Glass	0.75	B	10	3
4	Walk	0.9	B	10	3
5	Force Door (3in metal)	0	B	30	9
6	Crawl (10m)	0.5	B	20	6
7	Force Door (6in metal)	0.9	B	60	18
8	Run to asset	0	B	5	1.5
	Probability of Interruption	0.137438069			

8. CONCLUSION

In the proposed method, each of the tasks is independent. However it is envisaged that future models can include some task dependencies. The probabilities of communication and reaction time have fixed values. Evolutionary algorithms can be used to find the desired optimal values, as desired. Instead of the user manually entering the values for different paths into the computer program, or run a spread sheet program, an algorithm can be used to search the security space for the path with the greatest or smallest probability of interruption. Further, we should be able to find variations showing most vulnerable paths in the facility. This would be a path or paths that have a low probability of interruption. A user then can decide to change the placement of a sensor device, or add new once to improve the security. Both recent developments and our research in the project's field provide very encouraging results. However, more investigation is required before full confidence and wider acceptance of the approach is to take place in the ICT security industry.

ACKNOWLEDGMENTS

The authors would particularly like to thank Dr Perez Moses for his valuable ideas, observations and comments related to this work.

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CAPABILITY AND MATURITY MODEL FOR SIMULATION-BASED ACQUISITION: CASE STUDY IN KOREA

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ABSTRACT

Modeling and simulation (M&S) and simulation-based acquisition (SBA) methods are widely used in the military sector for weapons system acquisition. Capability and maturity measuring models are also widely accepted in processes of software development. These capability and maturity models, which evaluate strategies to drive results and improve SBA-related processes, are required to perform successful SBA. This study proposes a framework of capability maturity models for M&S development and SBA. We also define processes related to M&S development and stages of SBA in entirety. The ultimate purpose of the proposed model is to improve these processes. We provide applications and survey results to verify the proposed model.

Keywords: capability and maturity models, process improvement, simulation-based acquisition, modeling and simulation, needs planning

1. INTRODUCTION

Modeling and simulation (M&S) enhances innovation in defense acquisition processes in the military sector (Johnson, McKeon and Szanto 1998). The M&S paradigm is advantageous in a number of ways, including that it enables continuous appraisal of system development, rapid conceptual design, reduced time for making prototypes, continuous user participation in the development process, efficient manufacturing planning, and the provision of reusable software and hardware in training simulators (Fallin 1997; Zittel 2001). Acquisition activity based on the M&S paradigm had been also defined as simulation-based acquisition (SBA). Recently, unifying of those two terminologies, M&S is only used by many countries. Nevertheless, since the 'SBA' is still used in Korea, we also employ the terminology in this paper. Existing research on utilizing M&S and SBA intends to make active progress for the performance of efficient defense acquisition (Chadwick 2007; Keane, Lutz, Myers, and Coolahan 2000; Kratz and Buckingham 2010; Sanders 1997). To perform successful SBA, maturity models for measuring and appraising the capacity of associated processes are needed to ensure continuous process improvement.

Maturity models are used for process appraisal and improvement in a variety of fields. Examples of maturity models include the capability maturity model (CMM), capability maturity model integration (CMMI), and ISO/IEC 15504 (software process improvement and capacity entertainment, also known as SPICE). Among these models, we have identified the CMMI as having the proper method for process improvement, because the CMMI incorporates the advantages of the other models in one complete methodology. This paper, after examining the existing maturity models, proposes an efficient maturity model for SBA. As the first step, the framework of a capability and maturity model for SBA and M&S development is constructed, and the processes related to those areas are defined. Subsequently, we provide an instance for application to the needs planning stage of the model, which is an important step of SBA lifecycle procedures..

In brief, our proposed model can be regarded as an expansion of the CMMI model. Although our model is based on the CMMI, our research makes new attempts for the sake of efficiency. Considering suitability and flexibility, we develop a framework for our model, and divide the model into each of the steps of the SBA lifecycle. We also define the proposed processes, and accordingly, develop best practices related to the SBA lifecycle and M&S development. The advantage of our model is that we introduce a logical and proper model, based on the CMMI, which has been verified and is currently used publicly. In addition, our modeling considers actual circumstances to enhance the applicability of the final result. The model can be employed by communities or military agencies to improve both organizational and individual capabilities.
The paper is divided into six sections. Section 2 introduces the existing maturity models and examines their characteristics. Section 3 constructs a framework for our capability and maturity model for SBA and M&S development. Section 4 provides some examples of sub-models, which are used as guidelines for process improvement. Section 5 illustrates numerical results from surveys of M&S experts, and section 6 concludes our study and discusses future work.

2. EXISTING PROCESS MATURITY MODELS

We examine various maturity models in order to explain the concept of the maturity model and confirm its applicability to M&S. Details of CMMI and ISO/IEC 15504 are discussed and other maturity models are presented.

2.1. CMMI Model

Various difficulties such as quality, schedule, and cost are encountered in software development projects. To overcome these problems, the Department of Defense (DoD) in the United States, together with the Software Engineering Institute (SEI) at Carnegie Mellon University (Paulk, Curtis, Chrissis and Weber 1993; Paulk, Weber, Garcia, Chrissis and Bush 1993) developed the software-CMM (SW-CMM), which is a capability and maturity model for process improvement in software development. A study by Humphrey (Humphrey 1989) established the concept of SW-CMM based on the five-level model for the organization of quality management originally suggested by Crosby (Crosby 1979), and applied this model to organizing software development. Expanding the SW-CMM to system development and integration in 2002, DoD developed CMMI Ver.1.1. Three versions of this model – CMMI for Development (CMMI-DEV) (Chrissis, Konarad and Shrum 2006; CMMI Product Team 2010), CMMI for Acquisition (CMMI-ACQ) (CMMI Product Team 2010; Gallapher, Phillips and Richeter 2008), and CMMI for Service (CMMI-SVC) (CMMI Product Team 2010; Forrester, Buteau and Shrum 2009) – classify the CMMI into areas of development, acquisition, and service. In summary, CMMI is a process improvement maturity model for those three areas.

A special feature of the CMMI model is its methods of representation of maturity levels. The CMMI model has two methods for representing maturity. The methods are the continuous method and the staged method, both of which are illustrated in Figure 1. The staged method indicates the organizational level, while the continuous method indicates the area of process capability. The staged representation depicts the maturity of the whole organization, appraising the maturity level of an organization based on the accomplishment of objects for process areas in each stage. Since each maturity level is the basis for the next level, process improvement is obtained along a hierarchical structure. The visible advantage of the staged representation method is the possibility of comparison among organizations to indicate the regular abilities of the organizations. In the method of continuous representation, the level of capability is assessed in discrete process areas. The purpose of this method is to improve a particular process area. In the application of these two methods together, the CMMI achieves an appropriately complete method for assessing the conditions of organizations.

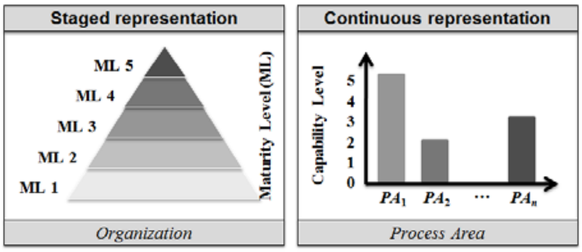

Figure 1: Two Representations of Maturity Levels Used in CMMI

2.2. ISO/IEC 15504 Model

The ISO/IEC 15504 reference model, also known as SPICE, includes processes and process properties to acquire, supply, develop, manage, and support the software in a specific organization (Doring 2007; El Emam and Brik 2000). During process assessment, assessors establish a suitable process assessment model based on a reference model in order to build up a common basis for decision making. To ensure compatibility between the assessment model and the reference model, SPICE describes the requirements for application. The common reference model provides a standard of assessment among results.

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2.3. Other Models

Other process maturity models are described in Table 1.

Table 1: Other Process Maturity Models

Model	Purpose
ISO/IEC 12207	Assess software lifecycles
ISO/IEC 15288	Assess system lifecycles
ISO 9001	Assess quality management systems
Malcolm Baldrige	Strengthen business competition in America
European Quality Award	Promote efficiency and efficacy of European businesses
Deming Prize (Japan)	Statistical quality control in Japan
Quality Management Prize (Korea)	Quality management in Korea

2.4. Consideration of Maturity Models for Simulation-based Acquisition

Given the typical structure of maturity models, all maturity models have two common properties. First is their common focus on process, and second is their common objective of process improvement. Because these two common features are coincident with the purpose of maturity models for SBA, we adapt these features to our proposed model. We examine the applicability to SBA of two typical maturity models, CMMI and SPICE, by observing their advantages and disadvantages. Table 2 shows their relative merits based on their properties. The underlined and boldfaced columns in Table 2 give the strengths of each model, for application to SBA, based on their properties. For example, the concept of a defined process in CMMI suits the procedures of SBA in that its use of identical process models decreases the cost of model development. SPICE allows flexibility because its process models are developed based on the target. With SPICE, however, there can be extra development costs and the imprint of the developer may affect the objectivity to the model.

Table 2: Properties of CMMI and SPICE

	CMMI	SPICE
Defined process	**Yes**	No
Reference model	**Identical**	Depends on the target
Assessment base	**Mostly identical**	Depends on the target
Flexibility	Weak	**Strong**
Costs	**Assessment costs**	Development and assessment costs
Factor of objectivity	**Assessor**	Model developer and assessor
Relative comparison	**Definite criteria**	Depends on the models
Training	**Periodical**	For each assessment

Considering these properties, our proposed model for SBA is a reference model that maintains the system of the CMMI model. Consequently, our model includes the advantages of CMMI as follows. First, CMMI is a set of best practices drawn from the successful completion of numerous projects and organizational processes. Next, the process areas in CMMI are analogous to SBA. That is, a number of process areas in SBA are related to process areas of CMMI-DEV and CMMI-ACQ. This similarity makes it possible to derive the core processes of SBA directly from the CMMI model. Furthermore, using already defined processes can reduce costs and support objectivity, which are advantages that cannot be achieved with SPICE. The defined processes also guarantee that definite assessment criteria are always identical and visible. This transparency makes it possible for anyone to be an assessor with simple training.

3. PROPOSED CAPABILITY AND MATURITY MODEL FOR SIMULATION-BASED ACQUISITION

3.1. Model Framework

This section describes the model framework of our maturity model for SBA, which is based on the CMMI model. To distinguish M&S development procedures from overall acquisition procedures, we use different terms. Specifically, M&S is the term for M&S development procedures, and SBA is the term for overall acquisition procedures. Accordingly, we classify capability and maturity models into SBA and M&S development according to their process properties. Figure 2 shows the framework of a capability and maturity model for SBA. The framework includes the model for M&S. This framework makes it possible to assess the M&S development of an organization, as well as to assess the main acquisition agencies.

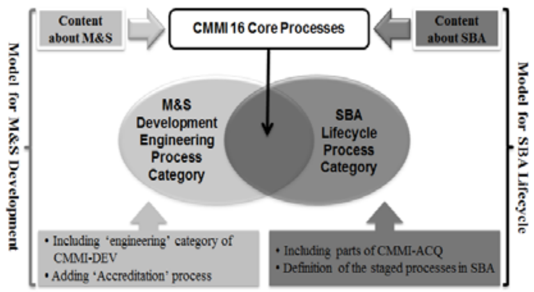

Figure 2: Framework of the Capability and Maturity Models for SBA

There are sixteen common core processes in CMMI-DEV, CMM-ACQ, and CMMI-SVC, which are directly applicable to every field without any modifications. Our model maintains these processes and adds specific processes of SBA and M&S development.

Adapting the category of engineering from CMMI-DEV to engineering for M&S development, we construct the maturity model for M&S development to additionally include the accreditation process that is requisite for developing M&S.

The entire category of SBA lifecycle processes includes some processes from existing CMMI models in order to retain their advantages. Defining the processes by phases in the SBA procedure, we reconstruct a process category that is specific to the SBA lifecycle.

Figure 3 illustrates the framework of the proposed model from a process viewpoint. The framework describes both process categories and processes in each category. In SBA, the integrated product team (IPT) controls all procedures of acquisition. The aspect of integrated product and process development (IPPD) makes it possible for the pending acquisition to take into account both the enhancement of overall military force and the performance of discrete weapons systems. The IPPD is a technique used by stakeholders for the procedure of acquisition in its entirety, to organize the IPT and to optimize the design, production, and maintenance processes of weapons systems. Therefore, our model connects the IPT to the area of organizational process definition (OPD). The OPD, which is a combination of processes supporting the SBA lifecycle, also includes acquisition support, which is defined as a process category. The OPD is one of the CMMI core processes, with an objective of establishing and maintaining organizational process assets and work standards.

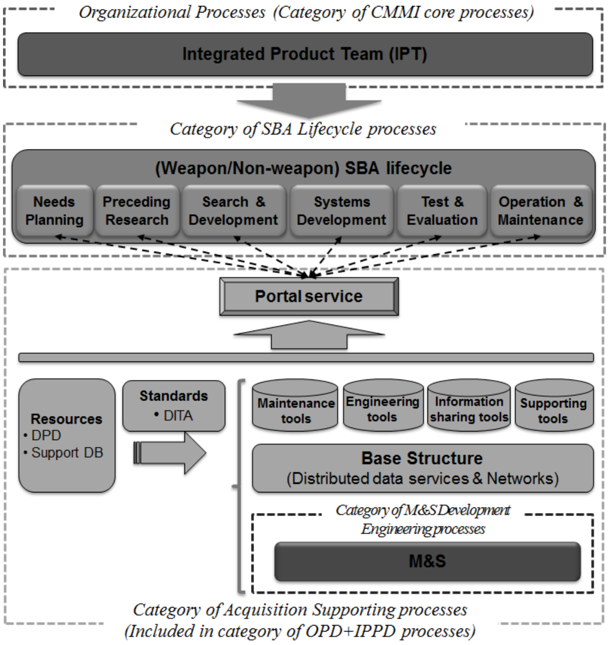

Figure 3: Framework of the Proposed Model from a Process Viewpoint

Table 3 defines the process categories that characterize the acquisition lifecycle. The SBA lifecycle consists of needs planning, preceding research, search and development, systems development, production, and operation and maintenance processes. To establish a reference for process improvement, we have defined appropriate process areas for each category as shown in Table 3. Because the initiative agency of each procedure in SBA is not uniform, we need to divide the model into six categories to assess relevant procedures. For example, if the Joint Chiefs of Staff require processes of needs planning, then the processes that fall within the "Needs Planning" category of the model's sixteen core processes can be used. The processes in each category are derived from existing CMMI models appropriate to corresponding SBA categories. The process with the same name as its category includes specified goals and best practices for successful achievement.

The process areas indicated in bold type are the specified processes related to each step of the SBA lifecycle. The rest of the process areas are derived from core processes of existing CMMI models.

Using or developing M&S is critically important for successful SBA. Fortunately, we can easily derive the processes of M&S development from those of CMMI-DEV due to their similarities.

Table 3: SBA Lifecycle Processes

Process category		Process area
SBA lifecycle	Needs Panning	Requirement Management
		Requirement Development
		Technical Solution
		Verification
		Validation
		Needs Planning
	Preceding Research	Requirement Management
		Requirement Development
		Solicitation and Supplier Agreement Development
		Technical Solution
		Verification
		Validation
		Preceding Research
	Search and Development	Requirement Management
		Product Integration
		Technical Solution
		Verification
		Validation
		Search and Development
	Systems Development	Product Integration
		Technical Solution
		Verification
		Validation
		Systems Development
	Production	Product Integration
		Technical Solution
		Verification
		Validation
		Production
	Operation and Maintenance	Requirement Management
		Requirement Development
		(Acquisition) Technical Solution
		(Acquisition) Verification
		(Acquisition) Validation
		Operation and Maintenance

We define several processes of M&S development engineering as shown in Table 4. The best practices from CMMI-DEV engineering can be applied without modification. Verification, validation, and accreditation (VV&A) are arguably the most important processes in M&S development (Balci 2003; Kilikauskas and Hall 2005). Accordingly, we define the accreditation process as the only process previously undefined by CMMI. The M&S development engineering model is independent from the SBA lifecycle model because it deals exclusively with M&S development. If an agency needs or wants to make a new M&S tool, this model is applicable to projects or organizations developing the tool.

Table 4: M&S Development Engineering Processes

Process category		Process area
M&S development enginerring	CMMI-DEV Engineering	Requirement Management
		Requirement Development
		Technical Solution
		Product Integration
		Verification
		Validation
	Accreditation	Accreditation

3.2. Hierarchical Structure

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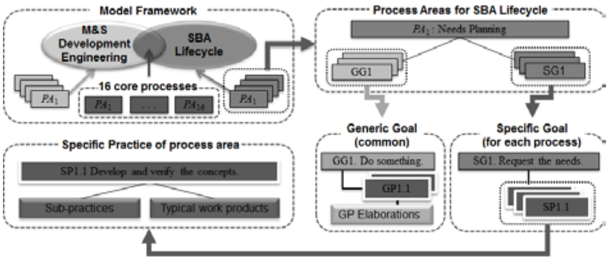

Figure 4: Hierarchical structure of the proposed model

The hierarchical structure of our proposed capability and maturity model is shown in Figure 4. As shown in the figure, the left topmost level is the framework, which includes the SBA lifecycle, the processes of M&S development engineering, and the sixteen core process areas. One process area that is called out in the figure is "Needs Planning", which the next section deals with as a specific model. Each process area consists of generic goals (GGs) and specific goals (SGs). These are standard units for determining and representing the assessed level of maturity. GGs are commonly applied to every process area, but each discrete process area has singular SGs. For example, "SG1. Request the needs" in Figure 4 is the first SG of the "Needs Planning" process area.

Because GGs and SGs are abstract requirements, concrete standards, called practices, are also needed for determining the capability of a process. Generic practices (GPs) and specific practices (SPs) support GGs and SGs. These practices are requisite conditions to achieve the larger goals (that is, the GGs and SGs). Therefore, satisfying the GPs or SPs implies the consequential achievement of associated GGs or SGs. For instance, "SP1.1 Develop and verify the concepts" in Figure 4 is an expected condition for accomplishing "SG1. Request the needs". Nevertheless, because the GPs and SPs are comprehensive, they must be supported by more informative activities. The activities are sub-practices, and their outputs are defined as typical work products. If the conditions of these activities are met, then the GP or SP is satisfied, and in turn, the GG or SG is achieved.

4. DETAILED INSTANCES

This section describes in detail instances of the proposed model for process improvement. The first step in the acquisition of weapons systems is needs planning. Needs are determined through the process of needs planning, which is a quite important step in the SBA lifecycle. Therefore, in order to describe the model in detail, we discuss some specific instances of the needs planning process. Table 5 shows specific instances of the "Needs Planning" process area.

Table 5: SGs and SPs in the "Needs Planning" Process Area

Needs Planning	
SG1	Request the needs : Make and request the needs
	SP 1.1 Develop and verify the concepts
	SP 1.2 Create the optimal needs
	SP 1.3 Analyze and evaluate the needs
SG2	Determine the needs: Investigate and determine the needs
	SP 2.1 Investigate the needs

The "Needs Planning" process consists of two SGs, each of which has three SPs and one SP, respectively. The process of needs planning is divided into aspects of requesting needs and determining needs, which equate to the specific goals of "Needs Planning". Each SP is an expected condition of achieving the corresponding SG. Most of all, the supporting informative activities are necessary for achieving the goals. We describe sub-practices and work products below.

The first SG is "Request the needs". The practices in this SG are arranged to appraise or improve the process, "Needs Planning". There are three SPs that describe the expected conditions for achieving SG1. Each SP is supported by informative activities, or sub-practices, some examples of which are subsequently described for each SP.

In SP 1.1, before developing the needs, the standard concept corresponding to the joint vision must be established. Next, the operating and functional concepts, as well as the integration of both concepts, should be developed in consideration of aspects of future wars (such as naval wars, ground wars, cyber wars, and space wars, among other examples) and the corresponding elements of force integration. Any joint operations concepts should be analyzed and operating scenarios should be developed through the utilization of theater models. Then, the operating and integration concepts should be investigated using mission, engagement, and engineering models. Engineering models are used to examine functional concepts. Finally, an integrated architecture based on the concepts should be reconstructed and verified around the interoperability of concepts integration (DiMario 2006; Sauser, Ramirez-Marquez, Magnaye and Tan 2008).

SP 1.2 describes the aspects of identifying optimal needs. To discover the optimal needs, we must identify the functions of battlefield alternatives, such as the functions of information, firepower, command and control, communication, and survival. Subsequently, the optimal solution should be determined by performing warfighting experimentation for these functional alternatives. Warfighting experimentation considers optimal strategy configurations and field operating conditions. The last step of determining optimal needs, after materializing the initial capability document for the systems which are to be developed or improved, is to draw up the optimal needs portfolio examining the acquisition criteria, including the time of weapons arrangement, method of acquisition, and quantities required.

SP 1.3 is the final step to analyze and evaluate the needs before formal request. To analyze the needs, performance measures for analysis and verification should be defined, including a measure of effectiveness (MOE), measure of performance (MOP), and measure of outcome (MOO). The MOE is produced by engagement models, MOP by engineering models, and MOO by mission or corps models.

The second SG is “Determine the needs”, which introduces the needs for investigation, and determines the needs. To achieve SG1, we should satisfy SP 2.1, which describes the practice for investigating the requested needs. Specialized analysis tools should be developed in order to investigate the needs scientifically and rationally.

More detailed description of those instances such as typical work products and subpractices are also available for each special practice in accordance with CMMI structure. For example, the charts of MOE, MOP, and MOO should be provided for SP 1.3 as typical work products. Those work products can be a basis or an index for quantifying the qualitative measure.

The instance described in this section is a part of the “Needs Planning” category, which composes a model for the optimal handling of needs planning processes. The model for needs planning consists of sixteen core processes and six special processes in the “Needs Planning” category, as shown in Table 3. That is, for successful needs planning, those particular processes should be improved. Because the other processes in this model are derived from the CMMI, the processes can be utilized as they are, with no modification required. Consequently, we can construct six models that are applicable to all of the steps of the SBA lifecycle, as shown in Table 3.

5. VERIFICATIONS

5.1. Survey and Statistical Model

To verify our proposed process models and practices, we conducted a survey with experts in SBA and M&S. We assessed expertise by simultaneously considering quantitative and qualitative indices in order to increase the objectivity of assessment. As quantitative indices of expertise level, the numbers of completed projects and published papers were used. We used four different academic degrees and three levels of self-evaluation of expertise as the qualitative indices.

The survey questions were organized as follows. First, after we introduced the “Needs Planning” process, we provided examples of SGs and SPs. For each SP, we listed questions for evaluating the importance of our developed practices as measured on a 5-point scale. At the end of the questions, we provided blank lines for respondents to fill in original recommended practices. We developed several versions of the question charts, corresponding to each of six categories and M&S development. However, since we focused only on the “Needs Planning” category as an example in the previous section, this section provides only its results.

To integrate and evaluate the importance of practices from the answers of respondents, we developed a method of integrated expertise and weighted average. This method integrates expertise as a weight, and calculates weighted average. Notations are defined as follows:

D_i : academic degree (1, 2, 3, 4)
M_i : number of SBA-related projects respondent has been responsible for
C_i : number of SBA-related projects respondent has been involved in as a participant
T_i : number of months in holding an SBA-related occupation
P_i : number of published papers relating to SBA
R_i : self-evaluated level of expertise (1, 2, 3)
n : total number of interviewees

To calculate the expertise of respondents, we used the standard formula,

$$M'_i = \frac{M_i - M_{\min}}{M_{\max} - M_{\min}} \tag{1}$$

where M_{max} and M_{min} indicate the maximum and minimum values of the M_i’s. Applying this formula to C_i, T_i, and P_i identically, we get C'_i, T'_i, and P'_i, the values of which vary from 0 to 1. Subsequently, we calculated S_i, the integrated expertise for interviewee i (i = 1, …, n), as follows.

$$S_i = D_i + 2M'_i + C'_i + 2T'_i + 2P'_i + R_i \tag{2}$$

To convert this value into a weight, we used

$$W_i = \frac{S_i}{\sum_{j=1}^{n} S_j} \quad (3)$$

where W_i is the weight of interviewee i. Finally, to calculate the weighted average, we used

I_{Qi}: level of importance from interviewee i for question Q (1, 2, 3, 4, 5).

Then, we calculated the weighted average by

$$IL_Q = \sum_{i=1}^{n} I_{Qi} \times W_i \quad (4)$$

where I_{Qi} is the final importance level of question Q. This final evaluation can be a basis of decision that the practice is effective to improve the corresponding process.

5.2. Results and Analysis

Based on the expertise integrated and weighted average technique, the results of the survey on SP1.1 about the "Needs Planning" process are shown in Table 6. The interviewees were selected from approximately 60 specialists in SBA and M&S. Figure 5 is a graphical representation of the information in Table 6. The column labels – from Pr. 1 to Pr. 6 – are the sub-practices described in Section 4. In Table 6, the first row represents results from the whole sample of interviewees (labeled "All interviewees"). Using the top 30 percent of the interviewees that ranked highly in expertise, we recalculated the importance levels of the proposed practices. The results of the recalculation are shown in the second row (labeled "Selected high rankers (30%)"). Since the values are similar to each other (by row), we confirm that experts commonly recognize the importance of each practice. All the measures for importance levels are relatively high, indicating that our proposed practices are coincident with the opinions of experts.

Table 6: Numerical Results from the Integration of Expertise Using the Weighted Average

	All interviewees	Selected high rankers (30%)
S.P 1.1	4.02	4.00
Pr.1	4.13	3.99
Pr.2	3.79	3.83
Pr.3	3.99	3.92
Pr.4	3.80	3.68
Pr.5	4.03	3.85
Pr.6	3.88	3.75

The results of SP1.2, SP1.3, and SP2.1 are omitted from further discussion because of their similarity with the results of SP1.1. The results of surveys about other processes are also omitted. All of the results show that our proposed models are applicable for improving the corresponding processes. Important recommendations from respondents collected in the blank lines section of the survey questions are included among our models. We are ready to verify the models again.

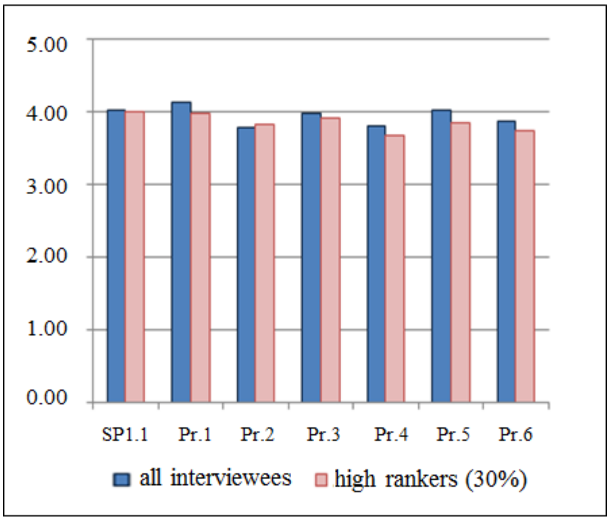

Figure 5: Graphical Representation of the Results, the Integration of Expertise Using the Weighted Average

6. CONCLUSIONS AND FUTURE WORKS

This study introduces a capability and maturity model for SBA. The proposed model is an expanded version of the CMMI model previously introduced by SEI. We defined the processes of the SBA lifecycle and set SGs to improve the processes. Subsequently, we developed SPs that describe important activities for achieving the SGs. Finally, we verified our model with M&S and SBA expert surveys. The proposed SPs can be used not only as assessment tools, but also as tests for process improvement.

By maintaining the advantages of existing models, we tried to overcome the limits that can occur while developing a maturity model for SBA. We also provided a flexible model framework to cope with new technologies. Our proposed M&S capability and maturity model can be used in various fields for acquisition of defense systems. For instance, companies developing weapons systems or M&S tools can apply our model to assess and improve their processes.

To enhance the proposed capability and maturity model for SBA, we must find and secure more sub-practices in support of every SP. In addition, since the proposed practices are appropriate for the Korean defense circumstances, more generalized practices which meet the common requirements of other countries should be developed. The active and positive participation of SBA agencies and M&S users in the real world is also extremely important in developing the model. Our research aims to provide a more advanced capability and maturity model for SBA in future studies.

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OPERATIONS ARCHITECTURE AND VECTOR FIELD GUIDANCE FOR THE RIVERSCOUT SUBSCALE UNMANNED SURFACE VEHICLE

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ABSTRACT
Full size and sub-scale unmanned surface vehicles (USVs) are increasingly used in a variety of tasks such as surveillance, patrolling and data gathering. Sub-scale USVs in particular are attractive for operations in protected waters because of their relatively low cost, stealth due to small size and operational flexibility. Typically the USVs are tele-operated, something that can create challenges because of their susceptibility to external disturbances, such wind and currents. Similar challenges apply to the design of the guidance laws utilized when the USV operates in partial autonomy modes. In this paper we describe the architecture of the Riverscout, a sub-scale, jet-powered, V-hull USV designed for protected water operations. The paper describes the overall system design with focus on the operational modes of the craft, the basic control scheme used for the boat's auto-pilot as well as the use of guidance vector fields for implementing waypoint following and loitering. Field data is provided to demonstrate the craft's performance.

Keywords: unmanned surface vehicle, guidance vector fields, partial autonomy, teleoperation.

1. INTRODUCTION

Unmanned surface vehicles (USVs) provide significant benefits in surveillance, patrolling and data gathering tasks. Equipped with appropriate sensors, they can gather data above, at, or below the water surface (Gadre, Kragelund, et. A., 2009) and convey such data to manned surface vehicles or central command and control stations. With the advent of sensor miniaturization and the associated reduced power requirements, sub-scale USVs have become extremely attractive alternatives for such tasks because of their smaller cost relative to the full scale vehicles, as well as their natural stealth due to their reduced size. At the same time, because of their smaller size they are significantly more susceptible to external disturbances (Yu, Bao, and Nonami 2008) and have reduced ability of handling high sea states. Sub-scale vehicles however can be used in rivers, harbors and other protected waters, something that addresses these key limitations.

Whereas the technical challenges associated with the development of sub-scale USVs are similar to the full size USVs, there are some differences that create unique challenges associated specifically with the lower cost, sub-scale USVs. First, due to the small size and reduced power budget, onboard computing resources must comply with the size and power limitations. Because such vehicles are typically remotely operated, it is important to identify an appropriate blend between manual and automatic operation which can support a given mission while minimizing the task load on the operator, (Enes, Book 2010). The susceptibility to external disturbances necessitates careful attention to the guidance algorithms used during autonomous modes of operation. At the same time, because such vehicles operate in relatively constrained environments, such as when going under bridges or traversing narrow pathways, it is important that any line following behavior minimizes path deviation, even in the presence of external disturbances. Similarly, when implementing a loitering behavior, which is typically defined as the behavior or remaining within a specific radius of a target location, the vehicle cannot simply stop. Wind and currents can quickly drift the vehicle beyond its intended position and because of the non-holonomic nature of a V-hull USV remaining within the intended region can become difficult.

In this paper, we describe the operations architecture and guidance approach used in a sub-scale, V-Hull USV platform called the Riverscout. The Riverscout was designed by the Carderock division of the Naval Surface Warfare Center. The Riverscout can carry a variety of payloads while operating in protected waters and under varying levels of autonomy. The architecture provides a variety of control modes, each with a different blend of operator and autonomous control. The guidance approach is designed around a set of hierarchical controllers which at a high level use guidance vector fields while at low level utilize classical cascade PID control loops.

The remaining of this paper is organized as follows: Section 2 provides background on similar work, focusing on using vector fields for guidance. Section 3 describes the boat, the control computer as well as the modes developed to support remote operation. Section 4 describes each of these modes and the controller formulation addressing each mode's requirements. Section 5 concludes the paper.

2. BACKGROUND AND RELATED WORK

The problem of planning a path for an unmanned vehicle and then ensuring that the vehicle follows that path is of enormous importance for aerial, ground, surface and sub-surface vehicles alike. Because of its importance it has received wide range attention in the traditional robotics literature, and most recently in the autonomous vehicles research, especially for non-holonomic vehicles. In general, researchers separate the task of developing a path from the task of following the path. In this paper we focus on the latter problem, because at this point, the generation of a path is left entirely to the human operator.

Several authors have addressed the problem of guidance and control of sub-scale USVs. Yu, Bao and Nonam (2008) developed a model for a sub-scale boat's horizontal motion and designed a controller to maintain course absent a heading sensor. Indiveri, Zizzari, and Mazzotta (2007) describe an approach to following a linear path taking into account the under-actuated nature of surface vehicles. Bibuli, Bruzzone, Caccia, Indiveri and Zizzari, (2008) provide a solution to the line following problem and show its applicability to the sub-scale Charlie USV. Sonnenburg, Gadre et al., (2010) compared a variety of experimentally developed models versus actual vehicle performance for 3 sub-scale USVs, concluding that for relatively high speeds in which GPS can provide course angle, steering dynamics can be approximate by a 1st order lag models for turn rate and sideslip.

Beyond surface vehicles, there has been a tremendous amount of work on control strategies for Unmanned Aerial Vehicles (UAVs). Despite the obvious differences, there are strong similarities between aerial and surface unmanned vehicles. This is because a significant amount of the literature focuses on the two dimensional movement of a UAV, treating elevation as constant. Furthermore, a surface vehicle aiming to remain in planing mode is subject to similar constraints as an aerial vehicle, namely minimum forward speed, and turning radius limits. Another shared characteristic between sub-scale aerial and surface vehicles is their susceptibility to external disturbances. One approach that has been used extensively for guiding small UAVs is guidance vector fields. In particular, it has been shown (Frew, Lawrence, 2005, Frew, Lawrence, and Morris 2006) that Lyapunov vector fields can provide globally stable convergence when guiding UAVs. As demonstrated in Frew, Lawrence, Dixon, Elston and Pisano (2007), an on-board controller guided by vectors fields can be treated as a new dynamic system by higher layers in the control architecture which can then provide high level guidance by simply adjusting a small number of parameters defining the vector field. This is advantageous because it provides a natural means for an operator to select the level at which to interact with the remote vehicle. The authors further demonstrate how flow field equations can be manipulated to warp the basic circular shape into a racetrack. A similar approach was used by Nelson, Barber, McLain, and Beard, 2006 to develop guidance fields for circular as well as linear paths, and the authors provide an algorithm that sequences a series of waypoints and generate the appropriate vector fields to guide a UAV along the waypoints.

3. THE RIVERSCOUT PLATFORM

3.1. Craft Description

The Riverscout is a V-Hull boat measuring approximately 1.6 meters long, 0.62 meters wide, and weighs less than 40 Kgms when fully loaded. The version of the boat described in this paper is propelled by two water-jets, each powered by a 5400 Watt (7.2 HP) AC motor for a total power capacity of 10800 Watts (14.4 HP). Each motor is powered by a dedicated battery bank with a storage capacity of 30 Ah per motor. Steering is implemented by vectoring the water thrust through lateral movement of the two output nozzles. This design provides a clean underside that only requires approximately 16.5 cm (6.5 in) of water depth for operation. A reversing bucket is utilized to allow the boat movement in reverse. The boat can operate in displacement and planing mode. The two modes have distinctly different responses, both in steering as well as thrust. Figure 1 depicts the boat while operating in displacement mode.

Figure 1: Riverscout in displacement mode.

When fully loaded, the boat transitions into planing mode at approximately 4 met/sec (7.8 knots). In planing mode, maximum speed is 10.8 met/sec (21 knots). Figure 2 depicts the boat while operating in planing mode.

Figure 2: Riverscout in planing mode.

The Riverscout can be equipped with a variety of payloads, each addressing specific mission requirements. Independent of payload, the vehicle is always under the supervision of a human operator, although it can operate in varying levels of autonomy. Supervision is facilitated by a set of cameras that are part of the payload. Common to all missions are the requirements that the craft operates in an automated mode performing line following while sequentially visiting waypoints, while having the option of loitering within a specific radius and for a specific amount of time at each waypoint. Beyond the automated mode, the craft also has the requirement of operating in a manual mode in which the operator dictates a heading and desired velocity (much like an auto-pilot) and finally, the craft can also be operated in a backup mode, in which the operator can directly manipulate the control surfaces.

In order to maintain the relatively low cost of the overall system, guidance and control functions were implemented using a network of two low cost micro-controllers. One microcontroller is dedicated to interfacing to the motors and other control servos, sensing craft temperature at multiple points, monitoring battery voltage and sensing motor rotational speed. A second microcontroller is dedicated to interfacing to the on-board Ethernet network, as well as the instrument CAN bus. In addition, all guidance control and autonomy functionality is implemented on the same microcontroller.

3.2. Operator Interface

Operation of the craft is managed by a hand-held computer that provides two thumb-operated self-centering joysticks, several buttons as well as a touch screen. The computer is running a dedicated Graphical User Interface (GUI) specifically designed to support a blend of the touch-screen and hardware interfaces.

The control GUI utilizes a two state design. The initial state is focused on ensuring the orderly startup of the craft and utilizes a virtual checklist that guides the user through the startup process. Process steps are checked off automatically when possible, and explicit user input is used when it is not possible to detect if a step has been completed.

Once the startup state is completed, the control GUI allows the user to control the craft in one of three control modes: Backup, Manual, and Route. These modes are described in more details in the Guidance and Control section of the paper. Independent of the control mode, the GUI provides to the user access to multiple screens, each selected through an on-screen tab. These screens include: Planning, Monitoring, and Video.

The Planning Screen is used to set up a route for the craft to follow when in route mode and allows for waypoints to be added. Waypoints are added to the map by either clicking on the map, or taking the craft's current location. Each waypoint can be customized with how fast the craft will approach the waypoint and how long the craft will loiter at the waypoint. A zero loiter duration indicates the craft should simply cross the waypoint. A non-zero loiter duration indicates that the craft will follow a circular path around the way point, in which case the radius of the loiter circle and desired speed during loitering can also be specified.

The Craft Monitoring Screen is used to display information about the internal status and operation of the craft. This information includes the battery level, internal temperatures, control settings, sensor information etc. An error log is also provided to list any errors (communication, sensor outages etc.) that have recently occurred.

The Video Screen is used to display the on-board camera views. The interface allows the user to select how the screen will be divided (single/double/triple or quad areas) and what is displayed in each of the areas. Any of the cameras feeds or the moving map display can be selected for display in each of the areas.

The craft is controlled through hardware buttons and two joysticks. The left joystick controls speed/throttle and the right joystick controls heading/steering. As an alternative to using the throttle joystick, there are 3 hard buttons available to control the speed. The buttons are for incrementing, decrementing, and stopping the craft. Several actions can be assigned directly to hard buttons, thus allowing the user to bypass screen controls for frequent actions or actions that require quick response. For example, a button is dedicated to zero the engine thrust and set the steering to straight, independent of the operating mode or status.

4. GUIDANCE AND CONTROL

4.1. Control Formulation

The three user control modes offered to the user are implemented by a set of on-board hierarchical controllers as shown in Figure 3. There are three operating modes, Backup, Manual and Route.

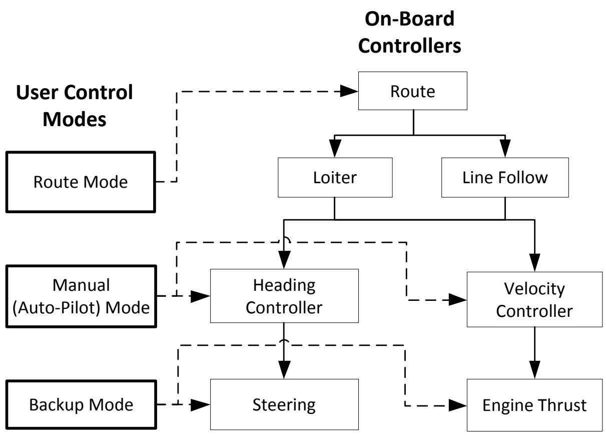

Figure 3: Heading Control Formulation.

The Backup mode is the lowest level and allows the user to directly control the actuators. The Manual mode allows the user to define a target speed and heading and uses on-board controllers to achieve the desired goal. The Route mode is the highest level mode and allows the user to specify a path to be followed. Each of these modes is further described below.

4.1.1. Backup Operating Mode

The lower level mode allows the user to directly manipulate the steering and engine thrust. Because this mode does not depend on any sensor information for feedback, it is meant to provide a backup control mode in case of sensor or navigation system failure, or for testing and diagnostics.

4.1.2. Manual Operating Mode

The Manual mode of operation allows the user to specify a desired heading and velocity without having to manage the control actuators directly. As explained in the user interface section, the hand-held control computer provides self-centering joysticks as well as discrete buttons for controlling the boat. In manual mode, discrete button clicks are used to establish the desired velocity according to pre-programmed set points. The pre-specified set points are designed to exclude a range of speed around the transition from displacement to planing mode. This range of speed is the most inefficient because the boat has not planed, yet the required thrust is significantly higher compared to slightly lower speeds when the boat is entirely in displacement mode. Whereas an operator near the boat can observe this state and increase or decrease speed appropriately, the boat can operate far enough from the operator where such observation is not possible. By eliminating this inefficient speed range, the system ensures maximum endurance even when operating far from the human operator.

The low-level velocity controller is implemented by using a feed-forward open-loop controller augmented by a classical PID portion that uses gain scheduling. The feed forward component is used to improve response and provides the majority of the controller output, whereas the PID portion compensates for smaller errors caused by disturbances and changes in battery voltage. A look-up table of engine-effort and resultant velocity values is linearly interpolated to determine the feed-forward component. The PID controller uses gain scheduling to compensate for the different response of the craft in displacement and planing mode. The topology of the velocity controller is shown in Figure 4.

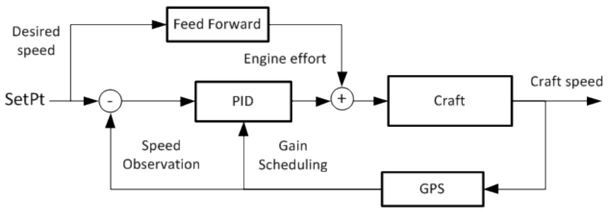

Figure 4: Velocity Control Formulation.

The performance of the velocity controller is shown in Figure 5. At speeds below 4 met/sec the boat is in displacement boat and the controller performs reasonably well both during increases and decreases in desired speed. When the speed exceeds 4.5 met/sec, the boat is in planing mode. There is a small amount of overshoot when the desired speed is set to 5.66 met/sec (11 knots) but again the controller performs adequately.

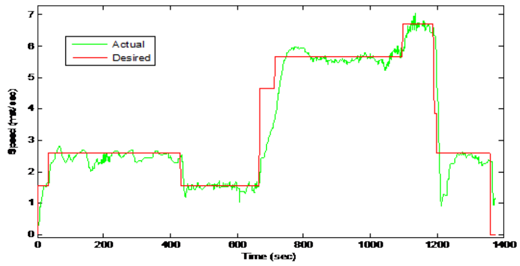

Figure 5: Velocity Tracking Performance.

A larger amount of undershoot is observed when the desired speed changes from 6.68 met/sec (13 knots) to 2.57 met/sec (5 knots). During that transition, the boat transitions from planing into displacement mode. The dynamics of that transition combined with the large discontinuity in the set point create a difficult transient. Even though this characteristic never became an issue during operational tests, we believe that additional gain calibration can significantly reduce undershoot.

The low level heading controller topology is shown in Figure 6. In Manual mode, heading is controlled through a self-centering joystick. When the joystick is centered a cascade controller topology is used; the front controller uses the heading error to derive a desired turning rate which is fed to the second controller which tracks it. When the joystick is depressed on either side, the displacement is scaled and used as direct input to the steering rate controller. The desired heading is maintained by a sample-and-hold subroutine. This subroutine monitors the release of the steering joystick at which point is samples and maintains the desired heading to be used as long as the steering joystick has no deflection.

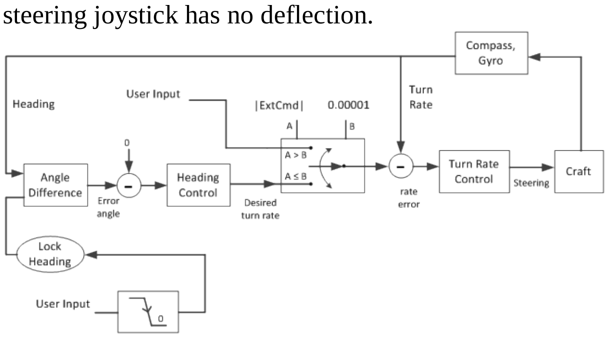

Figure 6: Heading Control Formulation.

This approach to controlling heading was found to be very natural for an operator. Simply releasing the joystick locks the boat on the current heading while moving the joystick on either side puts the boat on a best-effort constant rate turn which anecdotally has proven easier to handle for the operators.

The performance of the heading controller is shown in Figure 7. The top sub-plot shows the desired versus actual turning rate and the bottom plots shows the desired and achieved heading. This data was captured in route mode, hence the continuously adjusting desired heading.

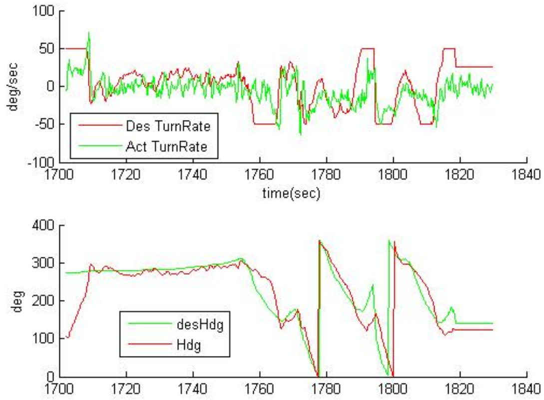

Figure 7: Steering Controller Performance

4.1.3. Route Operating Mode

In Route mode the boat follows a pre-specified route while maintaining speed constraints. The route is specified through a series of waypoints along with the desired travel speed between waypoints. At each waypoint, it is possible to specify two distinct behaviors. The default behavior is pass-through; once reaching the waypoint the boat will continue to the next waypoint. Alternatively, the boat can loiter for a pre-specified amount of time at that waypoint; once that time period has elapsed, the boat will continue to the next waypoint.

Because the Riverscout is designed to operate in relatively narrow bodies of water, it is important that the route following control strategy seeks to minimize the distance to each waypoint as it is visited but also the average distance to the line formed by successive waypoints. To achieve this goal, we utilize a strategy similar to what is described in Nelson, Barber, McLain, and Beard, 2006. This strategy utilizes a line-attracting flow field to guide the desired heading of the craft while transitioning between waypoints and a circular path flow field to guide the desired heading of the craft while loitering.

During loitering, we utilize a Lyapunov vector field as described in Frew, Lawrence et.al. 2007. For a counter-clockwise rotation, the field provides the instantaneous velocity for the boat:

$$\begin{bmatrix} \dot{x}_d \\ \dot{y}_d \end{bmatrix} = \frac{-\lambda v_0}{r(r^2 + R_L^2)} \begin{bmatrix} x_r(r^2 - R_L^2) + y_r 2rR_L \\ y_r(r^2 - R_L^2) + x_r 2rR_L \end{bmatrix} \quad (1)$$

In the above equation, R_L is the desired loiter radius, x_r and y_r are the x and y coordinate of the boat relative to the desired loiter center, *r* is the distance of the boat to the loiter center, and v_o is the desired loiter speed. The parameter λ (λ > 0) controls the gain at which the field converges to the circular path. For guiding the Riverscout, the loiter velocity is specified independently as part of the route description hence we set v_o to the value of 1 and determine the desired heading angle ϑ which is submitted to the heading controller as follows:

$$\partial = \arctan\left(\frac{\dot{y}_d}{\dot{x}_d}\right) \quad (2)$$

Figure 8 depicts an example of the vector field generated for circular loitering. Notice that when outside the loiter circle, the vector field guides to a tangent direction that minimizes turn rate transients.

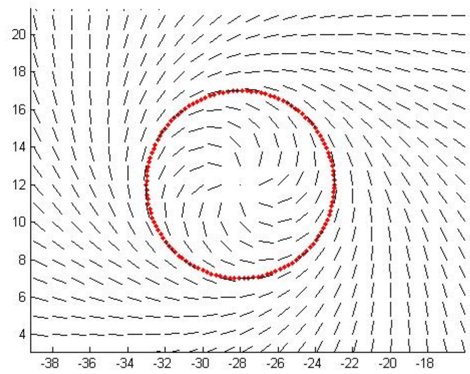

Figure 8: Loiter Vector Field.

During travel between waypoints w_1 and w_2, the vector field providing guidance to track the line (w_1, w_2) is generated by:

$$\partial = \partial_0 - \rho\theta_a\left(\frac{d}{\tau}\right)^k \quad (3)$$

where ϑ_0 is the angle of the (w_1, w_2) line, θ_a incidence angle that the boat follows when further from the line than d, which is the perpendicular distance between the boat and the line at which point the transition begins, t is the gain of the field heading transition between θ_a and ϑ_0. The value of ρ is given by

$$\rho = -sign(\overrightarrow{w_1 w_2} \times \overrightarrow{pp_p}) \quad (4)$$

where p is the position of the boat and p_p is the projection of the boat position onto the (w_1, w_2) line.

Figure 8 depicts an example of the field generated for transitioning between waypoints, using ϑ_0= 90 deg. d = 15 and τ = 1.1.

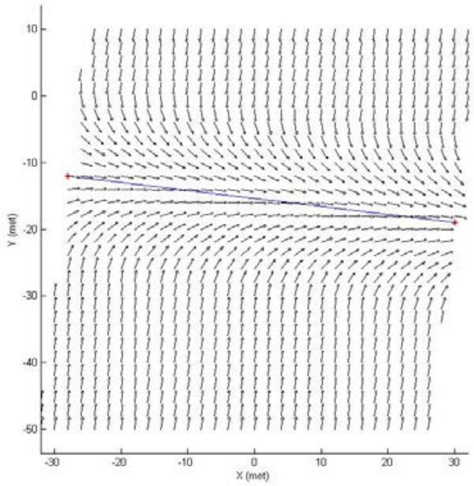

Figure 9: Line Vector Field.

To avoid situations where a large loiter radius forces the boat to deviation from the waypoint to waypoint centerline, the route guidance controller smoothly transitions from line following mode to loiter mode as the boat approaches the loiter position. Figure 10 depicts the path of boat while transitioning between two waypoints. The first waypoint is depicted by a red cross on the right side of the chart and the second waypoint and loiter radius is depicted on the left side of the chart. The wind was blowing N, NW at 15 knots during data collection, something that is affecting tracking; however the loitering pattern is clearly visible.

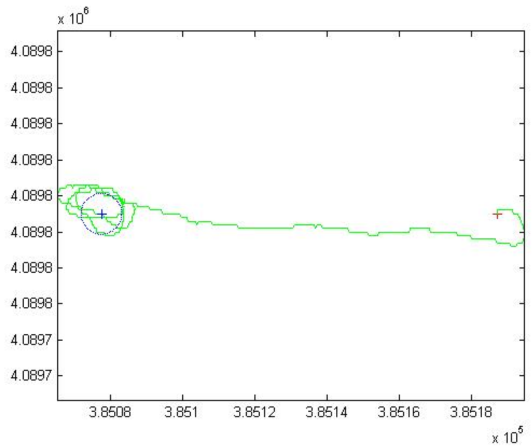

Figure 10: Line Vector Field.

ACKNOWLEDGMENTS
We would like to acknowledge the support of Naval Sea Systems Command, Carterock division for supporting this project.

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AGENT-BASED MODELLING IN THE NEW ZEALAND DEFENCE FORCE

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ABSTRACT
MANA (Map Aware Non-uniform Automata) is an agent-based distillation modelling environment developed by the Operations Analysis group at the Defence Technology Agency in New Zealand. MANA purposefully leaves out detailed physical attributes of the entities concerned if they are expected to have little bearing on the study at hand. This allows scenarios to be run relatively quickly, over many excursions (i.e. Monte Carlo simulation), in order to uncover capabilities or tactics where Blue can achieve dominance over Red. Another key feature of agent-based models is that, although the one-to-one interaction between various agents and their environment may be quite simple, the combined effect of many agent interactions can lead to complicated group dynamics and emergent behaviour. This paper provides the reader with an understanding of the philosophy behind the design of MANA, an overview of its features and some examples of its use.

Keywords: agent-based modelling, operations analysis, tactics, intangibles, defence, combat, capability, experimentation, technology.

1. INTRODUCTION

The Defence Technology Agency (DTA) provides applied research, exploratory development and policy studies on science and technology with application to military technology, force development and operational needs. Primary customers include the New Zealand Defence Force (NZDF) and the New Zealand Ministry of Defence (MOD). DTA also often partners with other government agencies and industry.

DTA employs approximately 70 scientists and engineers from a variety of disciplines. Research areas at DTA include operations analysis, sensor systems, electronic warfare, network systems, structures and materials, chemical and biological defence, undersea warfare, environmental science, human factors and autonomous systems.

1.1. DTA Strategic Position

DTA has a number of science and technology goals which are outlined as follows:

- Support current operations and capabilities
- Develop knowledge on emerging technologies
- Explore innovative and cost effective ways of employing technology
- Enhance force performance
- Support force development and capability acquisition
- Provide robust justification for future capability requirements
- Reduce the costs of acquisition and ownership of platforms and equipment
- Extend the life of platforms, weapons and systems
- Improve force sustainability
- Solve problems caused by New Zealand's unique strategic environment

1.2. Operations Analysis at DTA

The Operations Analysis group at DTA consists of 6 science researchers and acts as a conduit to other DTA science and technology expertise and to the international defence community. Key roles for this group include:

- Future concept exploration
- Capability methodology development
- Trade-off/balance of investment studies
- Experimentation methods and their execution
- Market surveys & technology assessments
- Supporting the development of operational tactics, techniques and procedures

The OA group intentionally therefore maintains a broad operational and strategic view to ensure the best overall NZDF and NZ Government outcomes by employing a range of tools and approaches. These include field experimentation, subject matter expert knowledge elicitation, modelling, simulation and wargaming.

1.3. NZDF Modelling Requirements

Models designed to represent complex adaptive systems produce results that are significantly different from conventional force-on-force combat models. The development of the Map-Aware Non-uniform Automata (MANA) modelling environment first began in 1999, after realising that such models better met the requirements of the NZDF (i.e. small unit operations).

2. MANA BACKGROUND

The history of physics has been characterised by the search for systems simple enough to be able to be accurately described by mathematical equations. Isaac Newton's laws of motion are an example. Although extremely accurate at predicting, for example, the path and distance travelled by a heavy projectile, they cannot in general be relied on if the projectile is light, has an irregular shape and is subjected to a turbulent atmosphere. This simple example illustrates a powerful point: that the world is often far more complicated than Newton's equations. To this day, there exists no set of equations that can with absolute certainty predict the evolution of the vast majority of phenomena we see in everyday life for any significant period into the future.

2.1. History

Our motivation for developing MANA began with a frustration with the highly physics-based combat models that were available to us at the time (e.g. CAEn and Janus).

Warfare is inherently chaotic, and although these models purport to be detailed, highly physics-based and rigorous, it became clear when one started to try to analyse the value of things such as human behaviour and knowledge-based warfare, they become quite limited. They also do not reflect the capabilities of the NZDF or the types of operations that the NZDF is principally involved in (e.g. peace keeping and humanitarian operations).

Moving to an agent-based modelling environment was driven by the key idea that the behaviour of entities (both friend and foe) was a critical component of the analysis of the possible outcomes. Distillation models also require less data and effort than high fidelity models, which better suited a small operational analysis group (Lauren 1999).

2.1.1. Agent-Based Models

MANA is in a general class of models called Agent-Based Models. These have the characteristic of containing entities that are controlled by decision-making algorithms. Hence an agent-based combat model contains entities representing military units that make their own decisions based on their situation, as opposed to the modeller explicitly determining their behaviour in advance.

3. THE MANA MODELLING ENVIRONMENT

MANA purposefully leaves out detailed physical attributes of the military entities concerned if they are expected to have little bearing on the study at hand. This allows scenarios to be run relatively quickly, over many excursions. Although it contains fairly simple input parameters, these can still result a surprisingly wide set of behaviours (Anderson et al 2004).

MANA is often used in conjunction with a technique known as Data Farming. This is an iterative process which uses the repeated execution of stochastic simulation models (such as MANA) to map out a problem landscape. The idea is that this can provide insights that may otherwise be overlooked by analysts.

3.1. Model Features

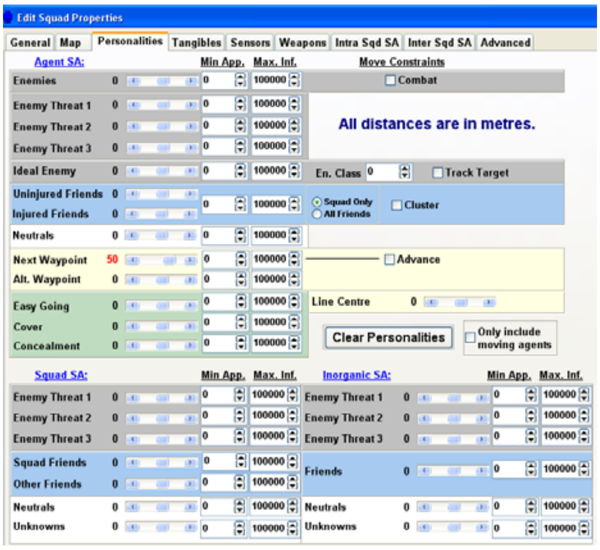

Figure 1: A screenshot of the MANA 'personalities' squad properties tab.

The *Personalities* squad properties tab determines an agent's propensity to move towards friendly, neutral or enemy units, waypoints and terrain features. Agents can either use information that is obtained individually (i.e. from the sensors they possess) or from other sources. Different personality states can also be triggered by battlefield events (such as being shot at). These can either affect an individual or a whole squad at once and will then last for a set timeframe.

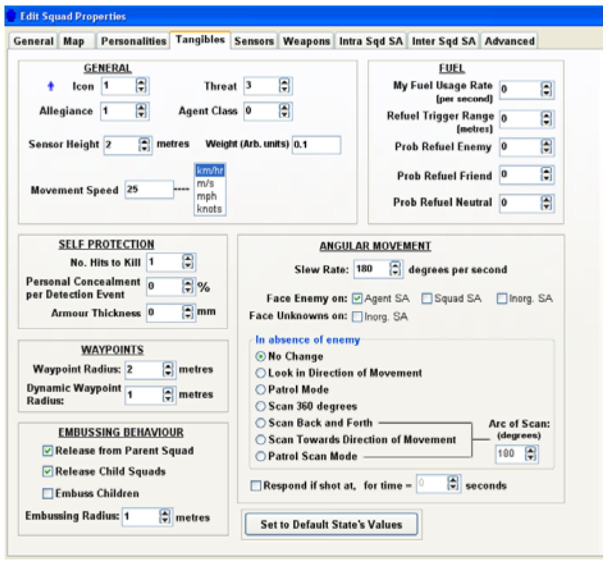

Figure 2: A screenshot of the MANA 'Tangibles' squad properties tab.

The *Tangibles* squad properties tab defines agent capabilities such as their allegiance (friendly, enemy or neutral), movement speed, inertia, endurance, concealment and protection (armour). It also contains parameters that can control the ability agents have to influence one other.

Users can choose from a built-in selection of icons to represent different agents or they can load in their own custom icons instead.

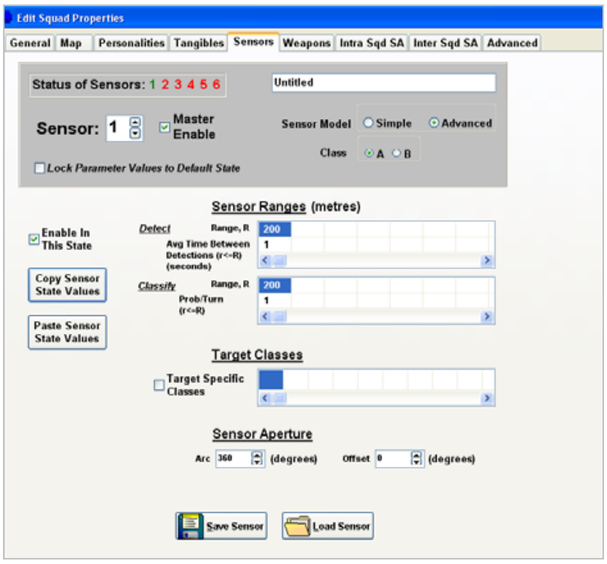

Figure 3: A screenshot of the MANA 'Sensors' squad properties tab.

The *Sensors* squad properties tab is used to define the sensing characteristics of agents. These can be represented with simple 'cookie-cutter' ranges for detection (unknown entity) and classification (allegiance is determined). Alternatively, advanced sensor options can also be used to introduce sensors that have a finite aperture (angle), range dependent probabilities of detection and integration times.

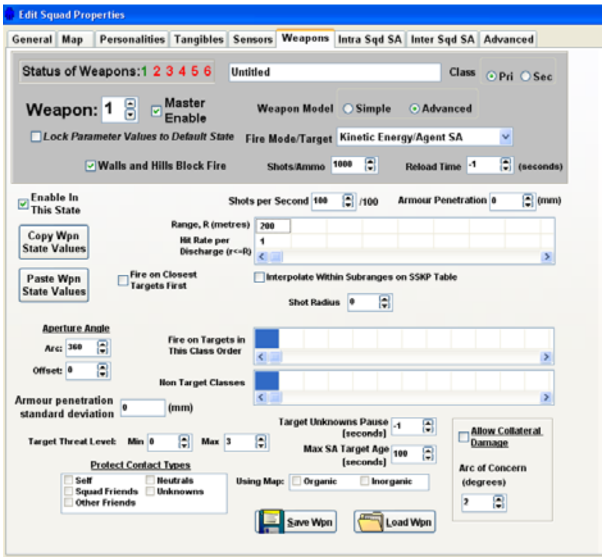

Figure 4: A screenshot of the MANA 'Weapons' squad properties tab.

The *Weapons* squad properties tab is used to define agent weapon capabilities. Weapons can either be direct (kinetic) or indirect (high explosive) in nature. Weapon parameters include ammunition levels, armour penetration characteristics and firing rates. Weapon employment rules can also be introduced, whereby targets can be prioritised by their distance and/or threat level. Options are also available to prevent agents from firing when there may be a risk of fratricide or collateral damage.

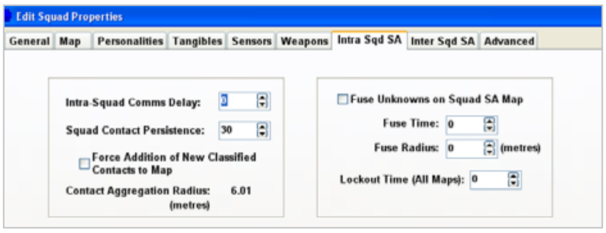

Figure 5: A screenshot of the MANA 'Intra squad situational awareness' squad properties tab.

Situational Awareness Maps are used by squads to maintain a group memory of detected contacts, along with whether they have been previously classified as friendly, neutral or enemy units. Users must select how often to update contact reports and maintain tracks for. Information can be shared between agents in the same squad (intra) or between agents in other squads (inter).

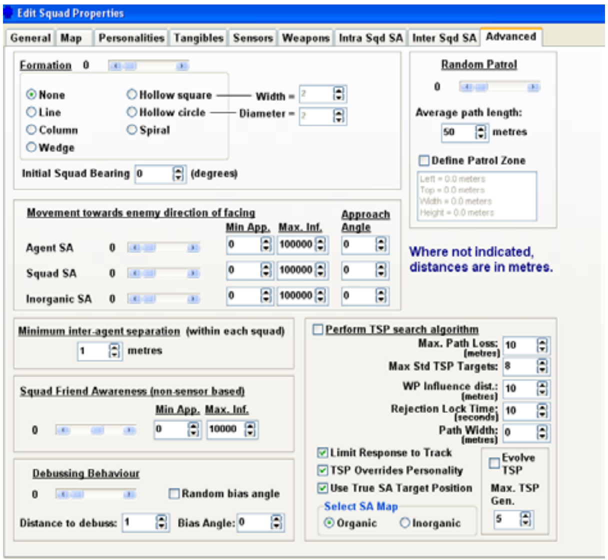

Figure 6: A screenshot of the MANA 'advanced' squad properties tab.

The *Advanced* squad properties tab is used to tweak the MANA agent movement algorithm. It enables users to force agents to maintain custom formations, separation distances and directionality. It also controls the degree of random movement (jitter) as agents move. A travelling salesman algorithm is also included, which gives agents a more sensible order in which to visit multiple contacts.

In addition to these tabs, MANA also incorporates tick boxes which can be used to disable certain attributes, such as line of sight calculations for sensors and communication links between agents. If these features are not required, then disabling them has been found to significantly speed up the run time of the model by reducing computational overheads.

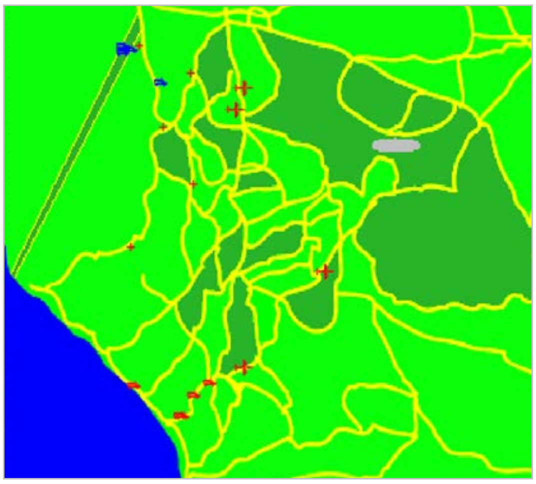

Figure 7: A screenshot of a MANA ‘terrain map’.

The *Terrain Map* is used to contain terrain features (e.g. roads, undergrowth, buildings) that agents can use to improve their mobility, concealment or protection. MANA includes a simple terrain map editor for adding such features into scenarios.

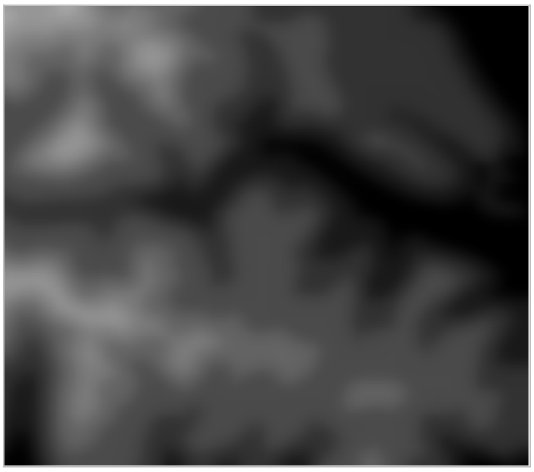

Figure 8: A screenshot of a MANA ‘elevation map’.

The *Elevation Map* is a grey-scale map which is used to define the height of terrain features. This will then influence agent line-of-sight calculations. A sensor height parameter can also be used to give agents the ability to see over obstacles and not be affected by terrain, for example, if they represent aircraft.

In addition to the terrain and elevation maps, a custom background image (e.g. a satellite image) can be used to give the scenario a more realistic appearance.

3.2. Recent Developments

- Genetic Algorithm tool: This gives MANA the ability to automatically mutate agent personality weightings over multiple generations to produce desirable outcomes. This could include maximising Red casualties, minimising Blue causalities or capturing designated battlefield spaces.
- Intelligent Path Finding: This feature uses wavelet principles to guide agents through complex terrain.
- Vector-based Movement: Version 5 of MANA implements vector-based movement. This resolved a number of issues attributed to the previous cell-based movement algorithms (such as diagonal movement and the scaling of maps).
- Operating System Enhancement: A version of MANA has recently been released for 64-bit operating systems.

4. NZDF APPLICATIONS OF MANA

Within the NZDF, MANA has been used to assist with identifying capability gaps, developing user requirements, evaluating tactics, techniques and procedures (TTPs) and in support of operations. Study topics have included:

- Maritime surveillance and patrols
- Land sensor mixes
- Cordon tactics
- Humanitarian assistance
- Maritime force protection
- Weapon effectiveness studies

Several specific examples are provided below.

4.1. Food Distribution Study (McIntosh 2004)

This study gives an example of how MANA can produce emergent behaviour, even with only a simple set of agent parameters being used.

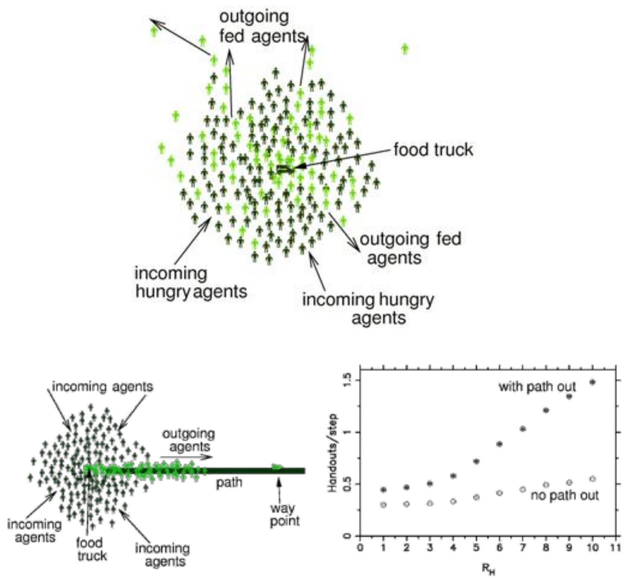

Figure 9: MANA food distribution study.

This study involved exploring strategies for food distribution in a humanitarian aid scenario. Only two personality weightings were given to the agents (get food when hungry and depart when fed) but one of the surprising observations was that agents tended to self-organise into temporary chains in order to get past one another (a phenomena that occurs in real crowds).

The results of this study showed that the food distribution rate depended most on controlling the outgoing flow of people rather than the incoming flow.

4.2. Land Sensor Mix (Anderson 2008)

This study gives an example of how the ‘distillation’ of a complex scenario can be used to enable different Red and Blue course of actions to be evaluated in a fairly short time period.

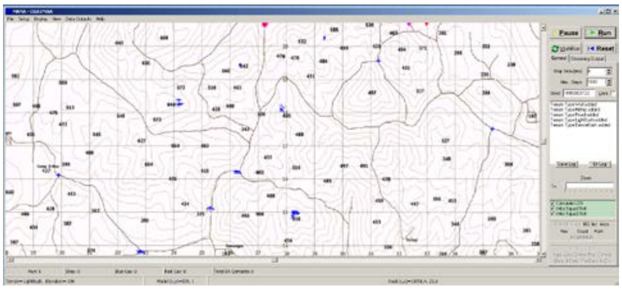

Figure 10: MANA sensor mix study

In this scenario, a motorised NZ platoon was given a screening mission near a rural village in undulating terrain (19 km wide by 7 km deep). Intelligence reports indicated insurgents with small arms were expected to try and infiltrate from the north on foot, giving Blue sufficient notice to deploy sensors and set up observation posts. Assets available to Blue included three light armoured vehicles, three remote ground sensors, five observation posts, a ground surveillance radar and a small tactical unmanned aerial vehicle (UAV).

An initial sensor deployment strategy was decided by the NZ Army during a tabletop exercise however during a subsequent wargame (using a virtual battlefield simulation) enemy units managed to slip through its sensor screen undetected.

MANA was employed post-activity to more thoroughly explore the effectiveness of the force structure. This was done by first using MANA to vary sensor placements and reduce the size of the area of operation (AO) until a maximum coverage rate was achieved. This was then employed against different enemy courses of action (random approaches).

The results indicated that too much emphasis in the original wargame had gone in to monitoring roads, and that the enemy force had exploited terrain features to avoid detection by going off-road. With revised sensor placements and the use of a slightly smaller AO size, MANA results suggested there was a 99% probability of detecting all the insurgents. Ground surveillance radar was found to be the most critical sensor to have (it contributed to 57% of the overall detections) and it was also useful for cueing the light armoured vehicles that were used to intercept Red. The UAV was found to be best utilised by using it to cover radar dead zones and to track contacts that moved through terrain where vehicles were unable to go.

The conclusion was that the proposed force structure appeared to be adequate for the given screening operation, but that some sensors had not been placed well during the original wargame. This highlighted the need for a more thorough intelligence preparation of the battlefield process.

4.3. Maritime Force Protection (Anderson 2012)

This study gives an example of how the data farming process and the inspection of extreme outliers can be used to gain tactical insights.

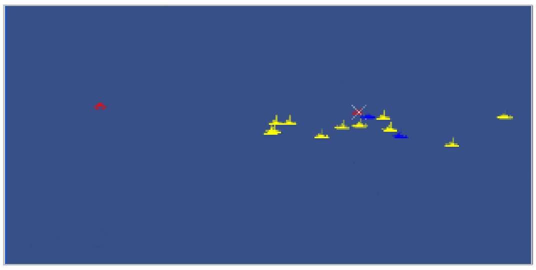

Figure 11: MANA anti-submarine warfare study

In this study, MANA was used to explore an anti-submarine warfare (ASW) scenario. In the scenario, warships must escort a convoy of 15 high value units (HVU) through a constrained waterway in which two enemy submarines were operating.

A baseline model was first run 500 times to determine the approximate number of Blue frigates required to protect the convoy. The main measures of effectiveness considered were the probability of raid annihilation (PRA) and the average number of HVU lost.

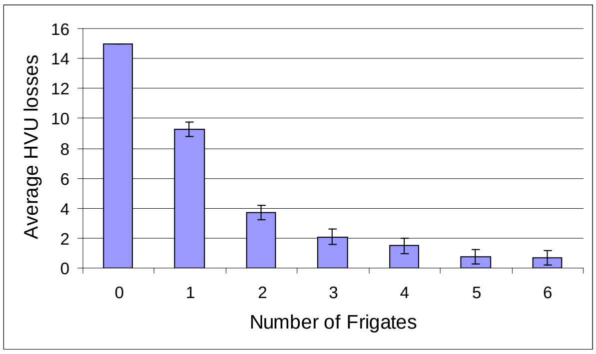

Figure 12: Baseline scenario results

The baseline model results suggested that four or more frigates were required to achieve a 100% PRA and that there was then a diminishing return on adding more frigates (having more than four frigates still resulted in the loss of at least one HVU). This was because Blue did not usually detect Red until after it launched a torpedo. A recommendation was therefore made to consider giving the HVUs their own torpedo counter-measures (e.g. towed decoys).

The inspection of statistical outliers also revealed key behaviours (tactics) that appeared to work well for both sides. For example, Red generally did better if it neutralised a frigate early in the scenario or if one sub could ‘distract’ frigates away from the convoy. Red also did well when it waited downstream for the high value units rather than closing in on them. Blue generally did better when the HVU convoy were clustered together and the frigates dispersed evenly around them.

A data-farming process was then employed, in which the baseline model was re-run multiple times across a wide range of incremental parameter changes. The entity parameters that were varied included; sensor and weapon ranges, weapon kill probabilities, firing time delays, speeds and starting positions. Regression analysis then indicated that detection range was the most critical parameter for Blue to have over Red, followed by weapon range, weapon kill probability and weapon firing cycle delay time.

5. SUMMARY

MANA has proven to be a highly flexible tool that has enabled DTA to conduct studies across a wide range of research areas of interest to the NZDF. Its rapid set up and turn around time has also made it a popular tool with the international analysis community.

In general, DTA has found that using MANA in conjunction with the data farming process can be extremely useful for gaining a better understanding of the key issues affecting the systems we are given to study. This has proved to be particularly useful to guide further research priorities and/or more in-depth modelling and simulation tools (Anderson 2012).

Because MANA also often produces a wider distribution of possible outcomes than other types of models, value can be gained from exploring extreme outliers and the interactions or events that led to their occurrence. MANA can also produce emergent behaviour that the analyst may not have previously considered. These types of insights can be particularly useful when analysing asymmetric warfare and counter-insurgency scenarios.

ACKNOWLEDGMENTS

The author wishes to acknowledge the work of Dr Gregory McIntosh, Dr David Galligan and Dr Michael Lauren in the development of the MANA model and their contributions to the examples presented.

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Mark Anderson holds an honours degree in engineering from the University of Canterbury and is currently a Senior Operations Analyst with the Defence Technology Agency (DTA) in New Zealand. He has a particular interest in the use of computer modelling and simulation to enhance military effectiveness and is one of the developers of the MANA agent-based combat model. His main research areas include weapon effectiveness studies, asymmetric warfare, sensor mix studies, logistics and unmanned aircraft systems.

MODELING AND SIMULATION OF LAND AVOIDANCE BEHAVIOR BELONGING TO TACTICAL ENTITIES WITHIN A HIGH-FIDELITY SIMULATION ENVIRONMENT

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ABSTRACT

The implementation of tactical entity land avoidance behavior integrated with realistic motion models is a crucial issue for a military simulation aiming high-fidelity. In this study, realistic surface platform land avoidance behavior has been implemented by utilizing a specific artificial intelligence path planning approach, namely, the vector field algorithm. The avoidance behavior is realized in conjunction with the automatic order execution behavior. A commercial simulation engine provided by the VR-Forces toolkit has been chosen for the implementation of computer-generated forces (CGF). Software modules and libraries for land avoidance as well as dynamic motion models and fuzzy controllers are all integrated into the component architecture of this CGF simulation engine. Results show that surface entities in the simulation exhibit realistic land avoidance behavior in parallel with order execution even in worst cases such as land crossing ordered paths and high ordered speeds.

Keywords: Land Avoidance, Vector Field Path Planning, Computer Generated Forces (CGF), Military Training Simulation

1. INTRODUCTION

Military training-critical simulation applications are utilized mainly because field exercises are too costly to be held for staff training, while high performance training results might only be obtained with high fidelity simulation.

In order to fulfill these high-fidelity constraints for military simulations, realistic CGF motion and control models should be implemented. Entities like surface platforms should overcome basic AI problems like land avoidance in addition to realistic dynamic motion and automatic order execution capability.

Land avoidance means handling the interaction of platforms with land realistically while the platforms continue to carry out their commanded tasks. Surface platforms should autonomously display avoidance from shallow waters with depth less than the platform draft. When it is impossible to stay away from land, such as when a platform positioned near to land is ordered to move directly towards land with maximum speed, land contact may not be prevented, which is but another realistic outcome.

This study aims to discuss the land avoidance behavior implemented in an on-going simulation system, which embodies a commercial CGF toolkit-integrated simulation of high-fidelity surface platforms. These platforms use complex motion equations and realistic fuzzy course and speed controllers which realize both mission execution and land avoidance behaviors.

For implementation, VR-Forces CGF unit has been chosen due to its easy customization and capability extension facilities. An HLA-compliant simulation environment, which uses RTI (Run-Time Infrastructure) for communication and coordination services, has been realized. HLA compliant simulations and currently offered HLA services are discussed in detail in Duman et al. (2003).

The VR-Forces based simulation components used in this study are front-end and back-end applications. The back-end application is where the actual CGF simulation takes place whereas the remote front-end GUI controls the back-end(s) existing in the whole simulation. The GUI application also provides features for scenario management and simulation execution control. The surface entities originally simulated by VR-Forces neither have movement models of appropriate fidelity nor exhibit realistic behavior such as land avoidance or fuzzy control. The details about the inner workings of VR-Forces architecture can be found in VR-Forces Developer's Guide (2006) or "VR-Forces The Complete Simulation Toolkit" article on the website belonging to the company named "MAK Technologies".

The software modules for the motion modeling and control of surface platforms have been implemented in the C++ programming language and have been integrated into the component architecture of VR-Forces CGF application (VR-Forces back-end) as composite objects.

The rest of the paper is divided into 4 sections. In Section 2, the land avoidance approach chosen in this study is given. Section 3 discusses the integration of land avoidance behavior into the simulated entity response. Section 4 explains the experimental setup and discusses the corresponding results. Finally, conclusions are given in Section 5.

2. LAND AVOIDANCE APPROACH

Automatic land avoidance problem is a specific type of path planning problem in the area of artificial intelligence (AI).

Among various methods in the literature, that attempt to solve the path planning problem, the vector field path planning algorithm, which is widely used in the field of autonomous robot control (Koren and Borenstein 1991; Khatib and Chatila 1995; Wolf, Robinson and Davies 2004), has been chosen as the most appropriate approach. It is mainly due to the fact that this algorithm is developed for predefined fields. Most of the calculations necessary for avoidance behavior can be executed off-line, increasing simulation performance.

A-star algorithm which is widely utilized for AI path planning problems is not suitable in these cases since high precision model platform behavior is required. Platform movement should highly depend on platform dynamics, so that a proper path cannot be dictated point by point.

VR-Forces CGF toolkit also provides land avoidance for entities by supplying information about whether land exists or not on a given trajectory vector. However, as platforms do not merely exhibit movement towards the bow direction, detection of land regions on one specific direction would not be sufficient enough. For the platforms to display sound land avoidance behavior where platforms not only avoid the coastal line, but also avoid regions shallower than their drafts, VR-Forces facility concerning just coast avoidance would not satisfy simulation needs. Vector field path planning is an appropriate solution considering these requirements.

The vector field path planning method identifies attraction and repulsion potentials and resultant commanded direction and speed for platforms are appeared to be the result of a weighted vector summation of these mostly conflicting potential force fields. Destination points or desired directions and commanded velocity values constitute the attraction potential for the platforms. On the other hand, a repulsion potential is generated by the obstacles on the field (namely the shallow waters and the coasts on the scenario map). Platforms behave according to the vector summation of these two potentials which is a function of the sea bottom, the current platform location and velocity. As a result, platforms execute their given orders while also avoiding land.

Repulsive normalized vectors for all possible platform coordinates are calculated beforehand with a certain resolution owing to the fact that all training fields are predefined. Afterwards, online land avoidance behavior is carried out by utilizing these previously computed data.

Land avoidance behavior is activated whenever the distance between platforms and shallow waters is less than 1 kilometer. This distance has been determined as an integer greater than the maximum stopping distance of all surface platforms. Avoidance vectors for all the points in the training fields are computed considering this maximum approach distance. Avoidance normalized vector calculation for each possible platform position is performed by taking into account all the land points in the square region of size 2 x 2 kilometers centered by the corresponding coordinate. The land points for surface platforms are defined as shallow waters with depth less than the average platform draft value (6m).

Avoidance value at a specific point is represented by a normalized avoidance potential vector (V_s). To obtain this vector, firstly, two dimensional gravity centers of the land regions inside the corresponding 2 x 2 kms. square is calculated. Then, the direction formed as a line between the gravity center and the possible platform coordinate is obtained. The value of the avoidance vector is inversely proportional to the distance between the two points. In other words, if this distance is minimum (0 km), then the value of the avoidance vector is 1, whereas if it is maximum (F2 km), then this value is calculated as 0. As a result the value of the normalized vector might be calculated with Equation 1.

$$| V_s | = (F2 - d)/ F2 \quad (1)$$

In the above equation, V_s is the normalized avoidance potential vector, while d is the distance between land gravity center and square center (platform location).

In Figure 1, approximate potential vectors calculated for different situations are visualized relative to each other. In the figure, the last scene displays the platform covered by land regions. In this special case, although the avoidance potential vector is at its maximum value, no avoidance is applied since the gravity center of land regions and the platform locations are the same and thus direction is undefined.

The next section begins with a brief overview of simulated surface platform components accomplishing commanded tasks. Then, the integration of the avoidance into the control mechanism of surface entities is explained.

3. INTEGRATION OF LAND AVOIDANCE BEHAVIOUR INTO THE SIMULATION MODELS

There are two main issues that must be taken into account to generate realistic navigation for surface platforms in military simulation systems: a high-fidelity motion model and a realistic control mechanism that provides the motion model with appropriate input parameters for completing commanded tasks. Surface platforms in the current system utilize a commercial toolkit independent software library that enables high-fidelity motion modeling. Details such as coordinate frames, motion equations, forces and moments acting on platforms along with simulation results are described in Haklidir, Aldogan and Tasdelen (2008). The software module for the motion model has been integrated into a specific VR-Forces component, namely an actuator component which is responsible for realizing the movement of the entity.

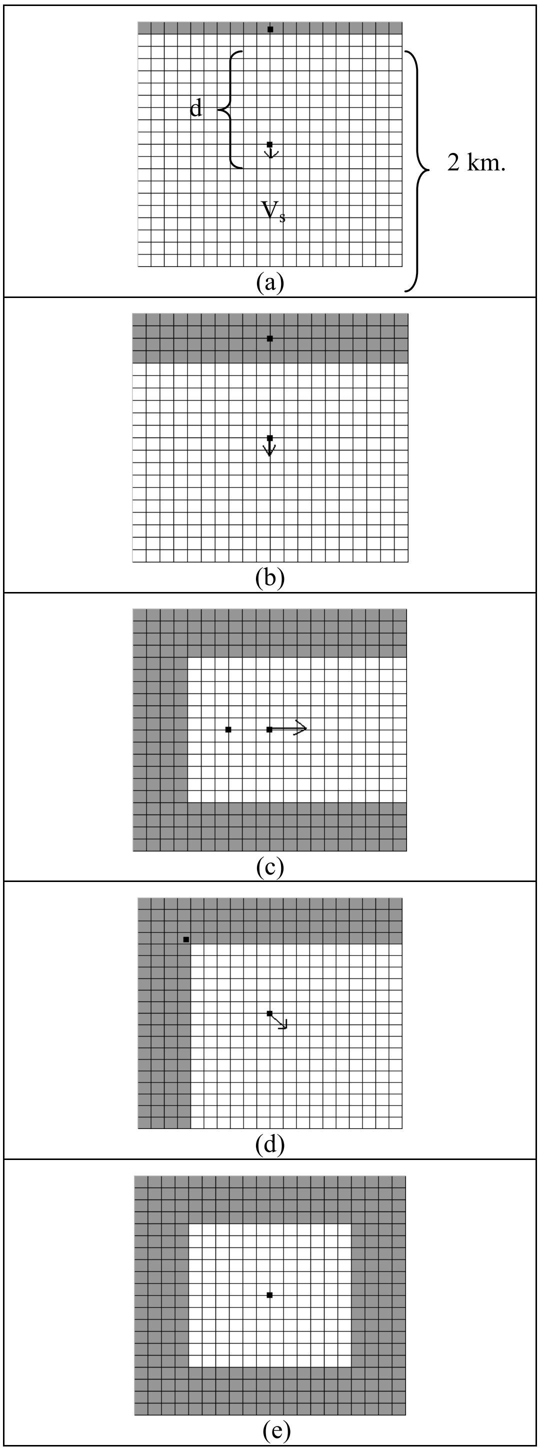

Figure 1: Representation of land avoidance potential vectors for different situations. Shaded regions represent land areas. The two marked points represent the gravity center of the land

region and the platform coordinates (central points).

In order to simulate quartermasters for the guidance of surface platforms, two distinct fuzzy logic controllers (FLC), namely heading and speed controllers, are utilized. These controllers obtain the desired heading and speed values corresponding to the current commanded task from the VR-Forces task controller. Afterwards, they calculate the necessary control parameters, i.e. rudder angle and shaft values, by utilizing one of the two different instances of a flexible fuzzy logic library (FLL). These two FLL instances are devoted to heading and speed control respectively and each of them are customized with a parameter and rule set in accordance with their specific type of control. A more detailed explanation as well as simulation results for FLC's can be found in Senyurek et al. (2008). After FLC's designate the values of the control parameters as a function of the inputted course and speed values and the current the state of the platform, platform's motion model receives these outcomes and calculates the next state according to the supplied control parameters.

The task control process deviates from its normal flow whenever there are land points within a certain range around the entity. In this case, current task related heading and speed values are first altered by land avoidance function and then are inputted to heading and speed FLCs as final desired heading and speed values. This process is accomplished in a way that permits the platform carry on its current task while causing it to exhibit adequate land avoidance behavior for fully simulating human expert behavior.

The task controllers in VR-Forces architecture are derived to encapsulate the land avoidance modeling along with fuzzy logic control just as VR-Forces actuator components have been derived to encapsulate motion models. Detailed information about the extension of the VR-Forces architecture and the integration of the software modules can be found in Aldogan et al. (2009).

Figure 2 displays the organizational structure of higher level task and avoidance controllers along with low level rudder and shaft controllers, each of which utilize low level FLL instances.

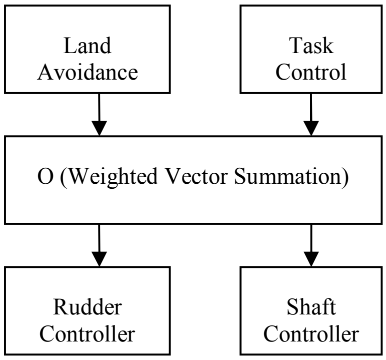

Figure 2: Organizational Structure of Controllers

The direction (L) and the speed (v_p) information dictated by the commanded task of the platform are united so as to form a task vector $V_g = [x_{vg}; y_{vg}]$ (eq. 2, eq. 3). This vector then undergoes vectorial summation with the scaled normalized avoidance potential vector (V_s). V_s is read from the database according to platform location and is scaled by an avoidance weight coefficient (k_s) (eq. 4). Direction and velocity information is retrieved from the summation vector (V_T) formed and is fed to rudder and shaft controllers as final demanded values.

$$|V_g| = v_p \quad (2)$$

$$y_{vg}/ x_{vg} = \tan(L) \quad (3)$$

$$V_T = V_g + k_s .\ V_s \quad (4)$$

Avoidance weight coefficient k_s should be directly proportional to the velocity of the platform (eq. 5). Since a platform that approaches towards land with maximum speed should apply maximum amount of avoidance, while a non-moving platform does not show any avoidance behavior at all.

$$k_s = k_1 .\ v_p\ (t) \quad (5)$$

A proper k_1 value might be obtained considering the worst-case scenario where the avoidance potential vector is at its maximum value ($d = 0$; $|V_s| = 1$). In such a case, automatic control must aim maximum velocity at the opposite direction in order to stop the platform that is moving towards the land region with maximum velocity (eq. 6). The symbol $V_p(t)$ refers to the velocity of the platform at time t.

$$V_T = - V_p (t) \quad (6)$$

As the platform is headed directly to land, it can be assumed that V_s and $V_p(t)$ vectors have the same direction. Since V_s having maximum normal gain is a unit vector ($|V_s| = 1$), it can be rewritten as a function of $V_p(t)$ vector and platform's current speed(7).

$$V_s = -V_p(t)/v_p(t) \quad (7)$$

The coefficient k1 can be calculated by placing k_s value calculated at eq. 5, V_T value calculated at eq. 6 and V_s value calculated at eq. 7 into eq. 4 while keeping the assumption that the commanded speed is achieved ($V_g = V_p(t)$) (eq. 8). Therefore, the avoidance weight coefficient (k_s) can be written in terms of platform's instant speed value $v_p(t)$ (eq. 9).

$$-V_p(t) = V_p(t) - k_1.\ v_p(t).V_p(t)/v_p(t)\ \text{P}\ \ k_1=2 \quad (8)$$

$$k_s = 2.v_p(t). \quad (9)$$

By placing the k_s value calculated with eq. 9 into eq. 4, the final desired velocity vector for the current situation(V_T) can be formulated in terms of the velocity vector corresponding to the commanded task(V_g), the normalized avoidance vector at platform's location (V_s) and the instant magnitude of the velocity vector of the platform ($v_p(t)$) (eq. 10). The total velocity vector calculated in this way is decomposed into its magnitude and angle values and these values are inputted to the shaft and rudder controllers respectively.

$$V_T = V_g + 2.v_p(t).\ V_s. \quad (10)$$

In order to maximize performance, the resultant vector calculation is performed only if there is land avoidance effect ($|V_s| > 0$) and the corresponding platform is moving ($v_p(t) > 0$).

4. EXPERIMENTS&DISCUSSION

Since the most fundamental aspect in this study is the land avoidance behavior of platforms, it must be verified that sea floor remains deeper than the draft during platform cruise.

The average draft has been set as 6 meters for surface platforms. The platforms shouldn't enter shallow waters while they approach their targets even when a route passing through land regions (islands etc.) is ordered.

In order to verify the land avoidance behavior of surface platforms, different platforms are commanded to move with different velocity and courses within the same test scenario. The sea floor depths of map points which the platforms are passing over are recorded into files during the scenario execution.

The test scenarios have been executed in the VR-Forces environment and recorded log files have been converted into figures by utilizing MATLAB 2007a. The map chosen for the test scenario, which contains sea depth information with 50m x 50 m resolution, covers a bay of Neverland with two small islands in the middle, one bigger island on the north and a cape on the south.

Figure 3 displays the initial state of the land avoidance test scenario. Surface platform 1 is commanded to move with a course of 80 degrees (wrt. north) so that its commanded route passes over the small islands. Surface platform 2 is ordered to move towards west so that the route given crosses the cape in the south. Surface Platform 3 is ordered to move to the waypoint named “Point 1”, while the bigger island lies between the platform and the waypoint. Surface platform 4 is commanded to move directly towards south so that the route given passes over the smaller island in the middle of the map. Surface platform 5 is ordered to move along a route that passes between the islands. Surface platform 6 is ordered to move towards east, in other words, directly towards the land region. Surface platform 7 is expected to move along a route that is directed to west and that crosses the cape in the south. Finally, surface platform 8 is commanded to move to a waypoint named “Point 2”, which is on shallow waters.

The initial heading values of all the platforms are in alignment with their ordered direction. Each platform is ordered to begin and continue movement with its maximum speed, which is dictated by the parameter set of its motion model and which is obviously the worst speed value for land avoidance performance.

Figure 4 shows the position and the orientation of entities approximately after 10 minutes of scenario execution. It can be observed that the platforms follow reasonable paths both considering land avoidance and order obedience. They head towards their goals by moving around islands and capes that cut their routes.

The platforms which are commanded to move directly towards the land regions with maximum speeds (Surface platforms 6 and 8) firstly slow down and maneuver but then crash to land. Figures 5, 8, 11, 14, 17, 20, 23 and 26 display the sea floor depth values of the points over which the platforms pass. It can be observed that during scenario execution, the floor depth remains more than 6 meters for all the platforms. The platforms that crash to land show a fixed sea floor depth of 6 meters after they run aground.

Figure 29 displays the followed trajectories of surface platforms. This figure along with the ones displaying bow direction and speed changes for each platform show that land avoidance is accomplished via acceptable course and speed deviations from the commanded values so that realistic behavior is maintained.

Surface Platform 2 slightly turns its bow direction towards north twice until it passes around the cape and tries to keep the commanded course of 270 degrees after each of these turns. Meanwhile, these maneuvers cause decreases in its speed. Once it passes around the cape, it manages to cruise with the commanded heading (270 degrees) and speed values (32 knots). Similarly, surface platforms 1, 3, 4, 5 and 7 also performed maneuvers to change their bow directions so that they can pass around land obstacles. Similarly, they decreased their speed during these maneuvers. After passing by land regions, they reached the commanded speed and bow direction values.

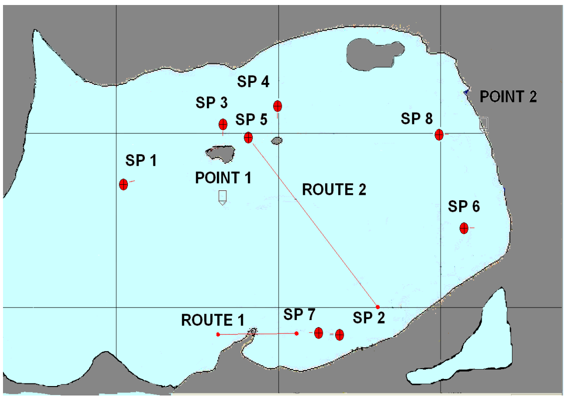

Figure 3. The initial state of the avoidance test scenario for surface platforms (SP refers to a Surface Platform)

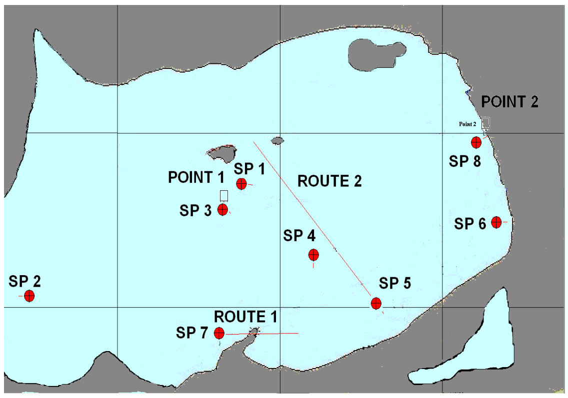

Figure 4. The final state of the land avoidance test scenario for surface platforms (SP refers to a Surface Platform)

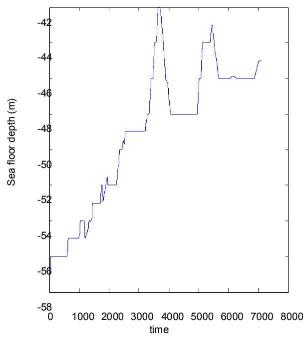

Figure 5. Sea floor depth for Surface Platform 1

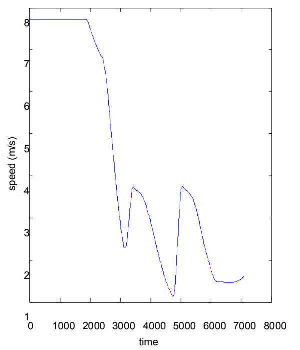

Figure 6. Speed change for Surface Platform 1

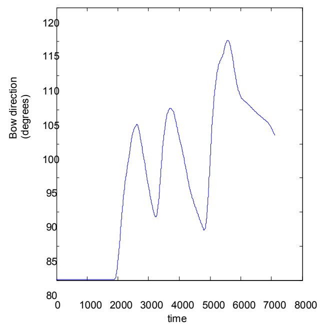

Figure 7. Bow direction change for Surface Platform 1

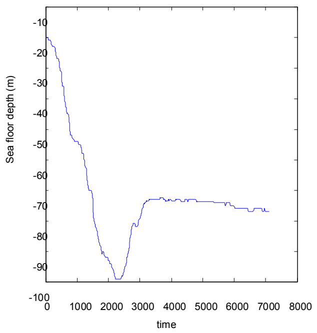

Figure 8. Sea floor depth for Surface Platform 2

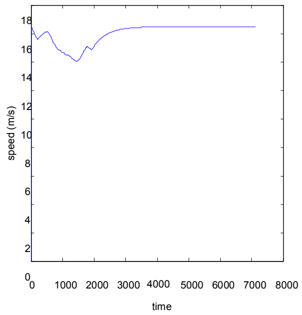

Figure 9. Speed change for Surface Platform 2

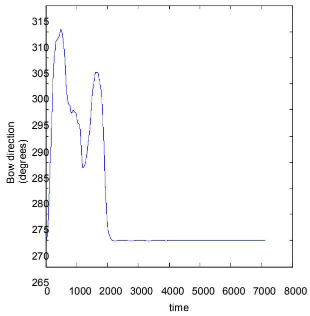

Figure 10. Bow direction change for Surface Platform 2

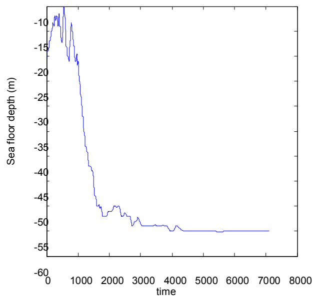

Figure 11. Sea floor depth for Surface Platform 3

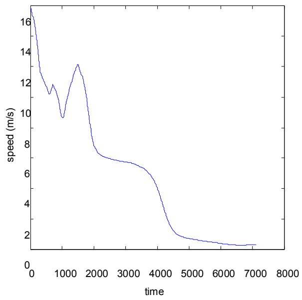

Figure 12. Speed change for Surface Platform 3

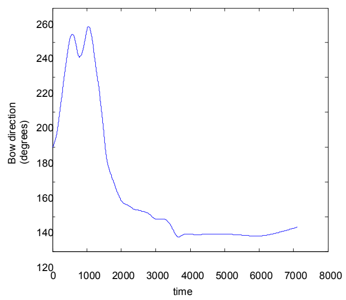

Figure 13. Bow direction change for Surface Platform 3

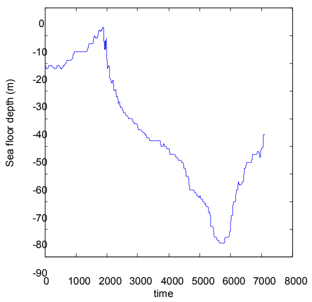

Figure 14. Sea floor depth for Surface Platform 4

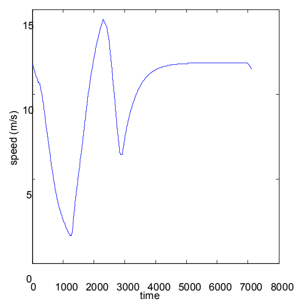

Figure 15. Speed change for Surface Platform 4

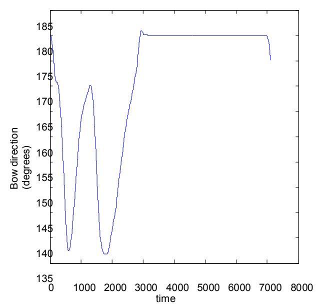

Figure 16. Bow direction change for Surface Platform 4

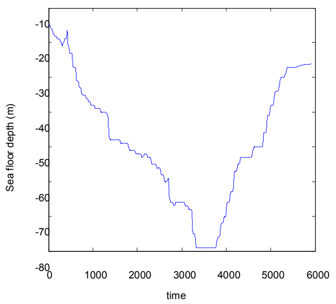

Figure 17. Sea floor depth for Surface Platform 5

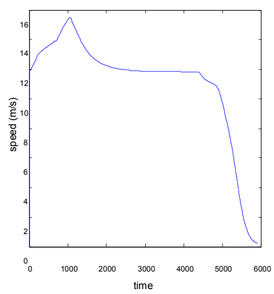

Figure 18. Speed change for Surface Platform 5

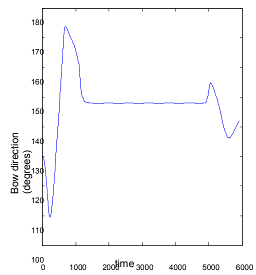

Figure 19. Bow direction change

for Surface Platform 5

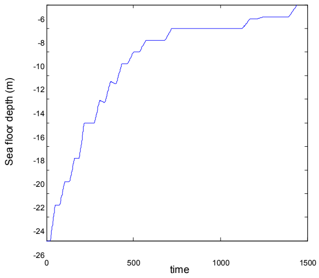

Figure 20. Sea floor depth for the Surface Platform 6

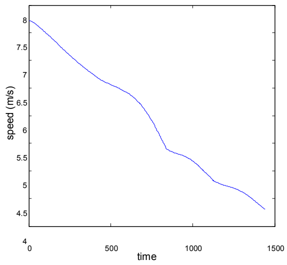

Figure 21. Speed change for Surface Platform 6

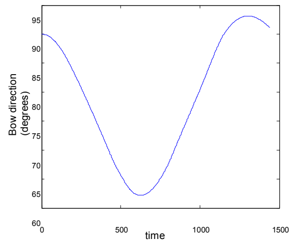

Figure 22. Bow direction change for Surface Platform 6

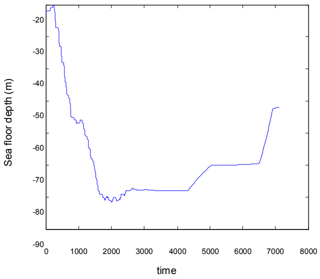

Figure 23. Sea floor depth for Surface Platform 7

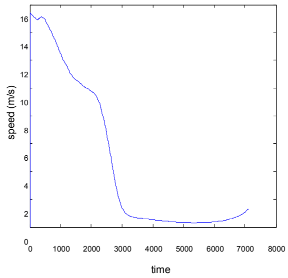

Figure 24. Speed change for Surface Platform 7

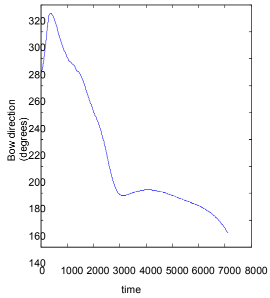

Figure 25. Bow direction change for Surface Platform 7

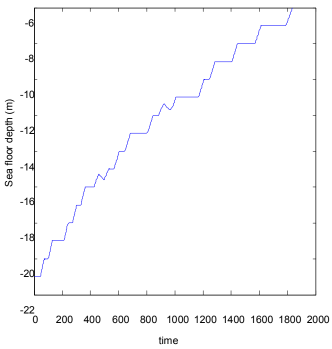

Figure 26. Sea floor depth for Surface Platform 8

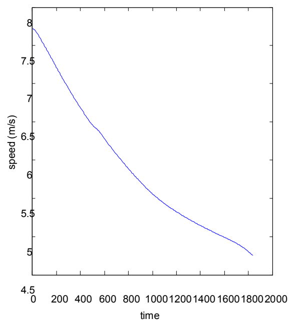

Figure 27. Speed change for Surface Platform 8

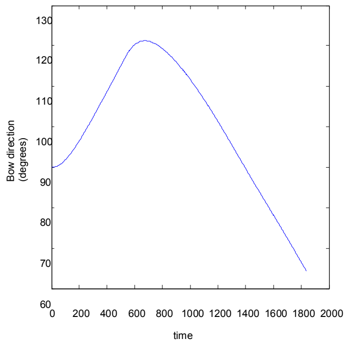

Figure 28. Bow direction change for Surface Platform 8

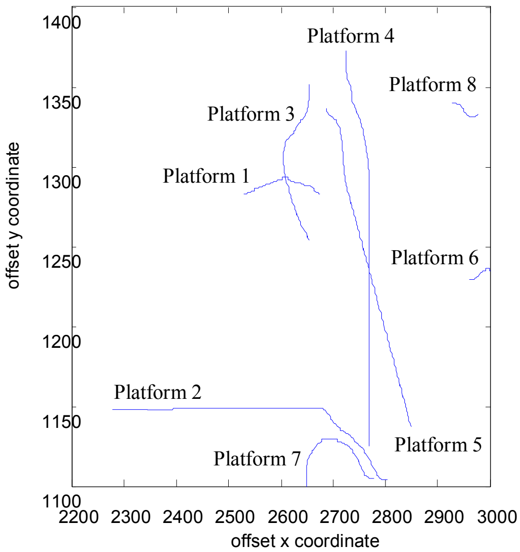

Figure 29: All followed trajectories belonging to the surface platforms during scenario execution

Since surface platforms 3, 5 and 7 are ordered to move to specific points on the map, namely to point 1 and to the end points of route 2, and route 1 respectively, during the last minutes of the scenario execution, their speed values approached to zero since they arrived at the commanded destination points. Surface platform 8, which began its movement at a point very close to the commanded waypoint and shallow waters, decelerated throughout its whole cruise time until it crashed to land. Likewise, surface platform 6 decelerated and changed its bow direction in order not to crash to land. These two platforms were positioned too close to shallow waters and were ordered to cruise towards land to assure that they run aground eventually. As a result, this special case of land interaction was also pointed out.

Data exhibiting platforms' behavioral details prove that the surface platform models in this study accomplish land avoidance behavior in a realistic way, via the simulation of a realistic quartermaster decision making process exploiting both fuzzy logic and vector field path planning.

5. CONCLUSIONS

This paper introduces an on-going study on a military training simulation system in which land avoidance behaviors are integrated into high fidelity motion models guided by fuzzy logic controllers. Thus, simulated entities accomplish both land avoidance and order execution while they preserve consistency with their dynamic models. In this way, it has been achieved to sufficiently mimic cruise control performed by platform captain and quartermaster. The whole design is integrated into the component architecture of VR-Forces, which provides a framework for developing Computer Generated Forces (CGF) applications. The overall integration has led the surface platforms of the VR-Forces application to reach high-fidelity which is vital for training-critical military simulations.

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ANTI-SUBMARINE WARFARE MODELING AND SIMULATION

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ABSTRACT

Submarines, modern naval warfare scenarios, especially in the context of asymmetric war remain the one of the most important platforms. Therefore, improvement of Anti-Submarine Warfare (ASW) capabilities is among the most crucial aims of many countries. In this field, they reduce the cost of training, reduced the potential risks and to provide a variety of tactical situations to military training purposes can be tried for fast simulation applications are more preferred to use.

In this simulation software study, complicated tactical situations can be simulated in various operating conditions and which involves tactical entities that can execute ASW commands autonomously, is explained. Surface, submarine, rotary-wing and fixed-wing platforms modeled in the current simulation system. These target platforms are equipped with various sensors, weapons and acoustic countermeasure systems. Target platforms can realize basic tasks such as moving towards a waypoint or along a path as well as complex tasks such as searching and engagement autonomously both individually and in groups called as *convoys*. Additionally, they can also display reflexive behaviors such as land, entity or enemy/torpedo avoidance. For managing scenario preparation and simulating Computer Generated Forces (CGF), the VR-Forces infrastructure, a commercial application framework, has been customized. The capabilities of the platforms developed to implement the software modules are integrated into the architecture of this infrastructure component CGF simulation engine. Results represent that platforms exhibit realistic behavior even in difficult conditions.

Keywords: Anti-Submarine Warfare, Modeling, Simulation, Virtual Forces

1. INTRODUCTION

In high-fidelity simulations, one of the most critical tasks that can be assigned to a simulation component is the modeling and simulation of different platforms. To provide high-fidelity, both realistic models and realistic controls should be employed for realizing the behavior of computer generated forces (CGF) in simulation. In addition to CGF capabilities, tactical simulations mostly require a scenario preparation application. Distributed simulation frameworks provide collaboration of different types of modules that have their own complicated modeling and algorithm mechanisms. We used a commercial simulation framework for this goal. This framework provides some basic abilities to all system; nevertheless, it is not possible to satisfy all necessities.

In this study, we shortly explain framework we used and modules that we integrated into that framework. Platforms we used have complex equations of motion and speed control, as well as they have various tasks such as move-to, search, engage. While performing main tasks platforms use fuzzy controller, land and other realistic targets avoidance behavior controller. Besides basic types of tasks we have convoy mechanism that we explained below. By the help of convoy mechanism platforms perform more complex tasks and act together in different situations. We designed and implemented our complex modules in different way and integrated them to main framework. Hereby, reusability and flexibility of software is achieved.

The software modules for the motion models, sensors, weapons and the fuzzy controllers belonging to platforms have been implemented in the C++ programming language and have been integrated to the component architecture of VR-Forces CGF application (VR-Forces back-end) as composite objects (VR-Forces Developer's Guide, 2006 ; VR-Forces The Complete Simulation Toolkit, accessed 2011). In addition to this, convoy mechanism and other complex task modules also implemented as separate modules and integrated to main software.

The remainder of this article is organized as follows. We briefly explain our main framework in section 2. In section 3, we explained artificial intelligence and tactical environment simulation. In section 4, we describe our main focus on convoy mechanisms and how to work complicated modules. In section 5, we explained our software design in detail. We illustrate some simulation results in section 6. Finally, section 7 concludes the article.

2. GENERAL SIMULATION ARCHITECTURE

In this study, movement models that take into account the environmental conditions (wave, current, wind, season, day and night difference) and hydrodynamic forces have been developed for surface, submarine and rotary wing platforms each with 6 degrees of freedom. The motion of all platforms is considered in 6 degrees of freedom since six independent coordinates are necessary to calculate state information of a rigid body. We explained in detail our previous work (Haklidir, Aldogan and Tasdelen, 2008; Franko, Koksal and Haklidir, 2009; Haklidir, Guven, Eroglu, Aldogan and Tasdelen, 2009)

Simulation architecture of VR-Forces, which is basically a commercial product being used in architecture, originally developed controllers and modules are integrated into this architecture.VR-Forces mainly have two main modules that are listed as back-end and front-end side. Front-end side provides management of scenario and simulation execution control. On the other hand, back-end side provides modeling and simulation of entities, controlling remote control entities, management of local entities' plan and all other issues such as task, set.

According to design of VR-Forces, each entity has three types of components: sensors, controllers and actuators. Sensors, allows you to retrieve information about the environment around the object. Controllers, receive information about assigned task and lead object for task. Actuators, organize task information, run motion model regularly and update objects' information such as speed, location. Commercial toolkit independent controllers are used to simulate quartermasters of the surface platforms. A flexible fuzzy logic that capable of simulating human expert behavior has been implemented. Fuzzy logic controllers, which are in fact heading and speed controllers that utilize fuzzy logic for their calculations, are implemented in conjunction with land avoidance calculations (Senyurek, Koksal, Genc, Aldogan and Haklidir, 2008).

Sensors have very important roles while platforms performing their task and making decisions. Each sensor component have been developed and integrated as a separate software module. Developing every advanced feature to be integrated into the entity behaviors as commercial toolkit independent software modules has been adopted throughout the realization of our system to maintain modularity and reusability. For further investigation, the reader can refer to our previous work (Aldogan, Haklidir, Senyurek, Koksal, Eroglu, Akdemir, Franko, Tasdelen and Akgun, 2009).

3. TACTICAL ENVIRONMENT SIMULATION AND ARTIFICIAL INTELLIGENCE

Utilization of modeling and simulation technologies in military areas is observed more frequently specifically on training and analysis applications. Creation of the tactical environment via Computer Generated Forces (CGF) and construction of war space with sensor and weapon capabilities of the entities in this environment has been seriously dealt with since 1980's and has come along crucial improvement processes up to now (Pratt, 1996; Kocabas and Oztemel, 1998).

The development of CGF can be analyzed in 5 subsequent phases. First generation CGF realizes scenarios simply without using behavior models. Second generation systems execute simple behavior models. Routes and roads are determined by the user before or during scenario run while interactions can only be on these structures. Third generation systems apply tasks which are composed of previously planned, rule or state based modules. In such systems, there is a hierarchy mechanism between tasks. Furthermore, these tasks can be applied in parallel or sequentially to form other complex tasks and behaviors. Fourth generation systems possess autonomous command control processes over advanced third generation systems. Fifth generation systems have capabilities such as goal selection or learning (Aldogan, Haklidir, Eroglu, Franko, Timar, Guven, Senyurek, Genc, 2013).

The system implemented in this study has abilities of a third generation system. The user is the decision mechanism in command control processes except a few reflexive situations (land avoidance, target avoidance, etc.). The user can decide on issues such as which entities will take place in a specific scenario, which capabilities and parameters the sensors and weapons of the entities will have or on which areas, roads or routes the task will be carried out. These decisions can be made before or during simulation run. Once decisions have been made, tasks are performed autonomously in accordance with the chosen task parameters and behavior models.

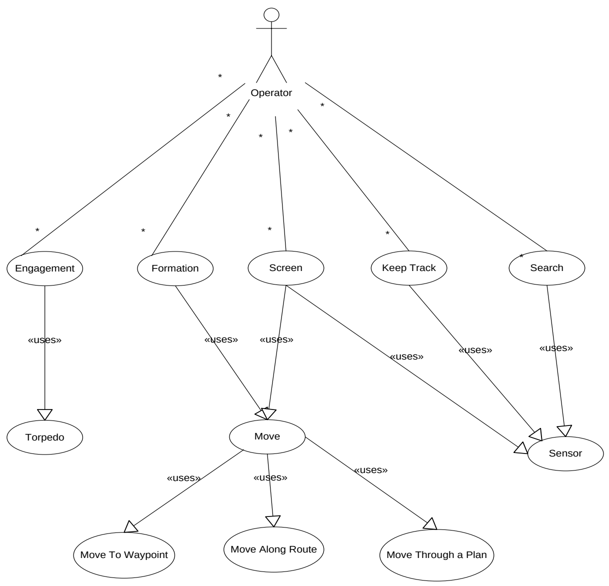

Figure 1 - Task and Behavior Hierarchy

Behaviors have been placed in task frames and these frames have been placed in other task frames. Therefore, main goals have been comprised of a task hierarchy. In this way, it is aimed to facilitate the construction of complex tasks and behaviors. The corresponding hierarchy is given in Figure 1.

4. ANTI-SUBMARINE WARFARE (ASW) CAPABILITY

4.1. Preferred Architecture and Basic Components for Implementing ASW Skills

A proper tactical training simulator should provide realistic target behaviour. Therefore ASW capability for marine ships and rotary wing platforms should be integrated into corresponding Artificial Intelligence (AI) models used in the training simulation.

As part of our work, requirements of ASW publications are surveyed for defining proper tactical behavior. Then, a set of basic actions are determined for developing a limited number of corresponding low level controllers which are used as building blocks to construct different complex tactical actions.

As a result, autonomous ASW capability of platform models is implemented considering an hierarchical behavior-based control architecture as in several other approaches in the literature (Michael, Henrik, Paul and John 2010; Krishnamurthy and Khorrami 2011; Aveek, Rafael, Vijay, James, John and Camillo 2002).

It is critical to properly determine the afore-mentioned basic/low level controllers to simplify the construction of complex behaviors. In our work we determined these controllers as a leader following controller. Speed controller for marine ships. For rotary platforms, leader following was unnecessary while an extra altitude controller was needed. These basic/low level controllers are constructed as fuzzy logic controllers for marine ships and as Linear Quadratic Regulator (LQR) controllers for rotary platforms. They all consist of separate components for speed and direction control.

For realistic response, land avoidance and conflict prevention behaviors for marine ships are also integrated into these basic actions. Land avoidance works in parallel with leader following and targeting behavior, as it controls the speed and direction of the models together with these controllers in a weighted manner. On the other hand, conflict prevention takes full control when necessary.

4.2. Constructing Complex Tactical ASW Capabilities

ASW tactics are applied by groups of platforms (marine ships and rotary wing platforms), which are called as *convoys* in these study.

Basic ASW behavior for a convoy is cruising in formation. For implementing such an action, convoy marine ships just apply the afore mentioned (low level) leader following control permanently. Both marine ships and rotary wing platforms might also be given screening duties, which is accomplished through (low level) targeting controllers. This time, for effective screening, several random target points inside a predetermined screen area are assigned to the corresponding models and each point is targeted one after another which is coordinated through high level screen controllers producing a realistic screening action.

Within the scope of ASW, applications of a search mission have similarities to convoy cruising. Searching is mainly cruising in an area with activated sensors, applying some special maneuvers if necessary. Again, each target model is assigned a set of target points which are visited in a specific order determined by high level search controllers. For accomplishing parallel search mission –another ASW search method– on the other hand, platforms apply targeting control for reaching their starting points in the first phase, while in the second phase they cruise parallel to each other exploiting basic formation control.

Similarly, for accomplishing convoy obstacle pass, basic behaviors are serialized in different phases. In the first phase each platform visits the canal points one by one while in the second phase they shift back to formation control.

Note that, applying leader following formation control does not necessarily need a leader platform to be determined. To accomplish most of the ASW tactics, imaginary leaders are created for more stable action, following similar works in the literature.

Attack missions have an additional attack phase in which platforms maneuver for assuring right conditions for weapon firing before firing their torpedoes'. This is also accomplished through basic targeting and altitude controllers.

4.3. Some Additional Information about Rotary Wing Platform Models Applying ASW

Rotary wing platform models, when arrived to a target point, hover at that point at a specified altitude and investigate their neighborhood via dipping sonar – which in our work is modeled as another mechanical element controlled by a separate controller applying the mission specific orders of the corresponding high level mission controller.

Since the flight time of rotary wing platforms are limited, they act in couples backing up each other coordinated by a high level controller for backup which is functioning in parallel with all the high level mission controllers for rotary wing platforms. Like other high level controllers this controller uses basic targeting and altitude controllers as well, for directing the models to proper targets –to a base ship or a mission point– when necessary.

5. SOFTWARE ARCITECTURE

Following sections will introduce the structure of the software components implemented to realize the ASW capabilities presented in the CGF. First section explains how a convoy of a several surface and rotary winged platforms is established. Secondly the high level mission controller and the low-level entity task controllers are described with their relations. Thirdly, rotary wing tasks explained. Lastly, we explained sensor fusion and tactical reflexive avoidance behaviors.

5.1. Convoy Generation, Update and Deletion

A convoy in the CGF is composed of entities of surface platform and/or winged platforms. Firstly the main ship of the convoy which can serve as a Leader is created or selected in the simulation environment and then the escort platforms are added to the convoy. All those entities are in relation to carry out escort tasks (low level) or convoy search and engagement missions (high level).

MainShip entity state repository includes the list of the escorts which are in the convoy. The escort entity state repository also includes the name of the mainship entity. This relationship is heavily used in the escort task controllers which require the mainship state as an input. Main ship state is also a reference for related algorithms especially leader following control.

In order to establish a convoy through the GUI and HLA1516, user input is transformed into interactions and objects that is processed by the CGF. The main interactions related with convoy generation and update are the selection of the main ship, adding escorts with a formation or screen mission, assigning search or engagement tasks to the convoy. Those interactions are first processed in the ASWCallbackHolder and ConvoyMapCallbackHolder which forms the necessary structure for entity tasks and controllers.

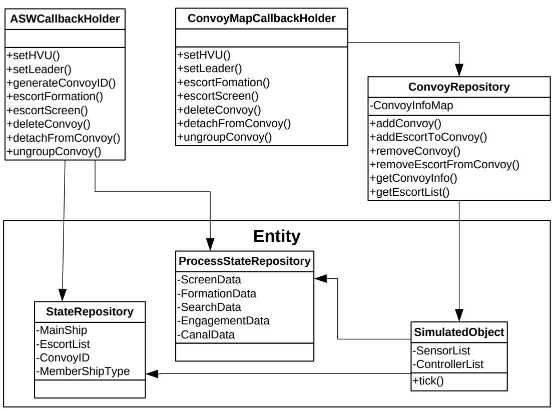

Figure 2 - Convoy Generation Information Flow

As you can see in the Figure 2, convoy generation interactions include selecting a mainship (setLeader, setHVU), adding escorts (escortFormation, escortScreen). User can also (1) delete an existing convoy (deleteConvoy) which deletes all of the entities from the simulated environment or (2) ungroup the convoy which makes all of the entities to end their convoy task or (3) detach an escort (detachFromConvoy) from the convoy. Interaction includes the information of which entity to be a leader/HVU, escort with formation and screen mission. According to this information ASWCallbackHolder updates the convoy identifier, and membership type of the related simulated entity. ConvoyMapCallbackHolder keeps all the relations of all of the convoys existing in the simulated environment in the Convoy Repository during runtime. Convoy sensor fusion or similar convoy mission/task managers which require all the entities of an existing convoy can query from ConvoyRepository.

5.2. Convoy Mission Control Architecture

ASW subsystem of the CGF enables the user to assign a group task to all or some of the escorts in a convoy. User interactions about a mission to search for a hostile subsurface entity in a specified region or a mission to engage to a hostile subsurface entity are first processed in the ASWCalbackHolder. The mission information (search/engagement region, selected escorts, etc.) is passed to the corresponding convoy task manager derived from BaseManager. You can see the various convoy task manager in Figure 3. BaseManager can access to ConvoyRepository to enable the task manager to query all of the convoys in the environment. Each convoy task manager assign the specific task to each escort to accomplish the convoy mission. This relationship is visualized in Figure 4. For example for a convoy to accomplish an engagement mission , ConvoyEngagementManager assign an attacker task to one escort and engagement task to the other escorts in the convoy which are selected to be a part of the mission.

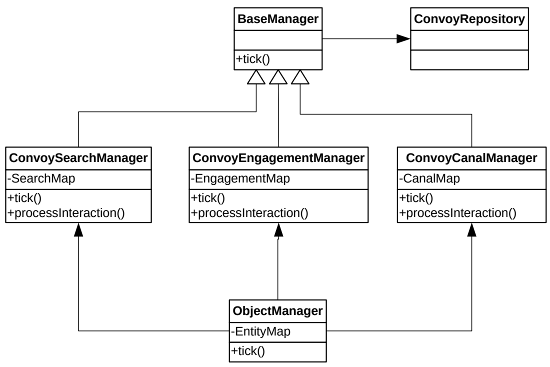

Figure 3 - Convoy Mission Architecture

ObjectManager, one of the most important classes of the CGF, executes each sensor, component and actuator of each entity in each simulation step. Convoy task managers are also executed by ObjectManager in each simulation step to handle convoy missions. The “tick()” function is overloaded in each task manager since it is executed in every simulation step.

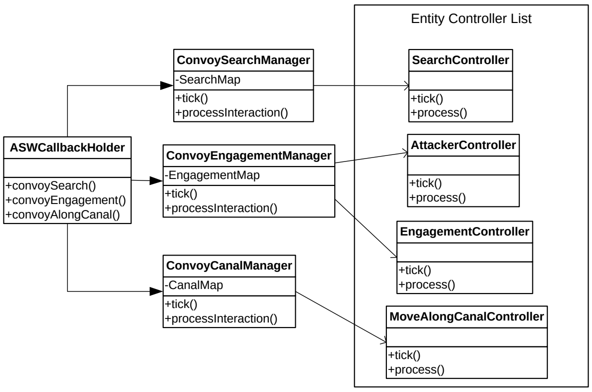

Figure 4 - Convoy Task Controller using Entity Task Controller

Escort task controllers are implemented using the existing task controller architecture to utilize the avoidance and dynamic models already implemented in the CGF. The relationship and the properties of the controllers are visualized in Figure 5. BaseController uses the CollisionAvoidance for calculating new routes to avoid colliding with the land or the other platforms in the environment. BaseController also executes AuxilaryController which calculates the basic state parameters of the platform model. Being inherited from BaseController, entity task controllers are driving the entity's behavior in a convoy mission in which several numbers of escorts are involved.

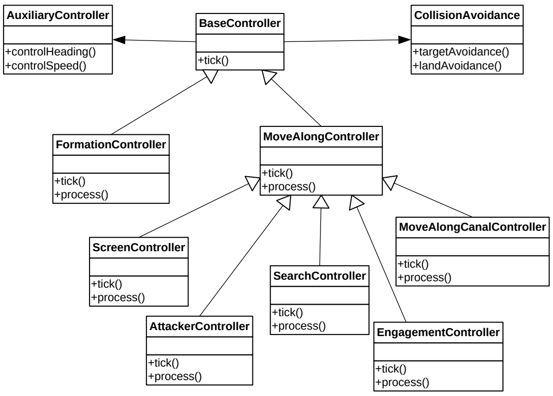

Figure 5 - The relationship and the properties of the controllers

5.3. ASW RotaryWing Tasks

The relationship and the in simulation environment combat ships have inventory helicopters. By using graphical interfaces, user can give screen, search or engagement tasks to inventory helicopters. After the task completion helicopters go back to their bases or user can stop task and command helicopter to return its base manually.

When user commands a task to rotary wing entity, graphical user interface sends the interaction to WingedCallbackHolder. This class collects winged entities' callbacks. User can command screen search task to helicopter. That interaction has the corner points' data of the search area. User can command a general search task which includes more general searching movements. After determination of the target platform user can command an engagement to target task. Engagement interaction includes approximate location, approximate bearing and possible route of target. Also torpedo attack points are passed.

As seen in Figure 6, callback holder's functions pass data to ASWManager class. ASWManager, which is inherited from BaseManager, evaluates the interaction data and processes controllers. Rotary wing platforms naturally exist in their ship base or land bases. When a search or engagement task is received, processTask runs and gives command to related controller (ScreenController, SearchController, EngagementController, ReturnToBaseController). If skipTask command is received, scheduleSkipTask method registers current timestamp. After 5 minutes of this timestamp helicopter's task will be stopped. Because of the operational time limitation, most of the helicopter tasks are paired tasks. When the flight time of a helicopter decreases to critical values its pair is commanded to continue the task.

ObjectManager, which controls all objects inside the simulation, runs its tick in every simulation step. Its tick also runs ASWManager's and other managers' ticks. ASWManager's tick checks and updates flight times of the helicopters. When needed it creates pair by using createPair, evaluates current task and pass current task parameters to pair helicopter. It also checks for the position of the new helicopter. If helicopter reaches pair's position, returnToBaseController runs, current helicopter returns to base for fuelling its fuel, torpedoes etc. Also user can stop helicopter's search missions in the middle of the task or delete inventory helicopter. In this case task is deleted and helicopter will be returned to its ship or land base.

Although callback holder and manager classes pass the commands, in most of the simulation time controller classes run. For instance if the task is screen, processTask of the ASWManager runs process method of the ScreenController. It assigns search points and dipping sonar depths to helicopter. After this initialization controller's tick runs each step. In each tick RotaryActuator is run. Actuator makes calculations and updates data in its state repository. State repository has heliData, taskData and motionData. HeliData includes helicopters name, id, pair number, current flight time, total flight time. Task data includes detailed task info and skip task's timestamp. Motion data includes linear position values, angular positions, linear and angular velocities of helicopter. Local network interface classes use these data and publish it to graphical user interface for operator information. Other controllers work similarly but their tick method implementations differ regarding to their algorithms.

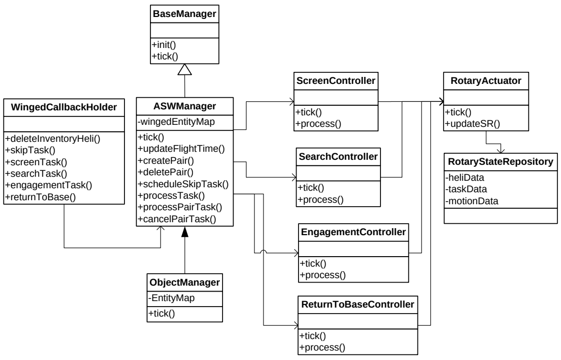

Figure 6 - Inventory Rotary Wings and Paired Tasks

5.4. Sensor Fusion and Tactical Reflexive Avoidance Behaviors

In this study, each entity of a scenario owns several sensors through which the entity may acquire detections of an enemy entity or its torpedoes in water. With the aid of a specific derived VR-Forces controller, namely the avoidance controller, a surface platform can halt performing its current task and make certain maneuvers in order to avoid from such a detected threat.

For entities that have been assigned in the same group, a sensor fusion manager module obtains all the sensor detections of these entities and inputs them to a sensor fusion algorithm in order to calculate an approximate location for the enemy entity or its torpedoes. After that, an avoidance manager module checks whether such a location has been detected for each entity group. For entity groups with a valid enemy detection, avoidance controllers of each entity in the group are evoked with necessary parameters.

Sensor fusion result for each entity group is also published in the simulation since it can be benefitted from while assigning certain search or engagement tasks. Once a corresponding location approximation can no longer be evaluated due to loss of detections in the sensors, a special point, namely the datum point, is displayed on the tactical screen for a predetermined amount of time.

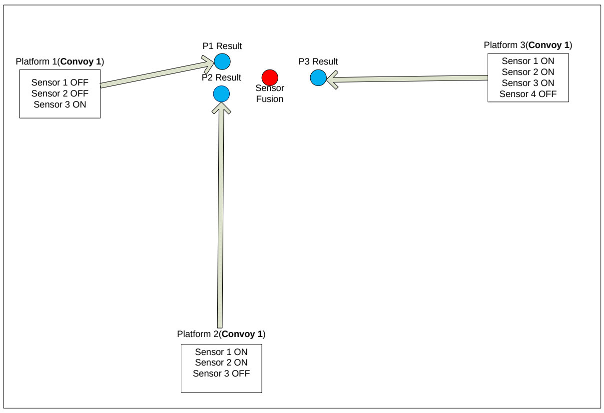

Figure 7 - Genereal Sensor Fusion Presentation

In Figure 7, there three types of platforms belong to same convoy (**Convoy 1**). Each platform has different types of platform and some of them ON and some of them are OFF. According their own algorithm they have their own sensor detection results. We implemented a algorithm that have input all platforms' sensor detection results (for this example, platform 1 result, platform 2 result and platform 3 result) and output *sensor fusion point*.

6. SIMULATION RESULTS

In previous section we explained in detail different types of modules we used. In this section, we illustrate some sample result about developed modules.

In Figure 8, we show an example those 2 platforms given search task. Originally those platforms have leader. Leader gives them a search task in geometrical region. According to their assigned region platforms first reach that region and then follow a pattern (as shown in figure, like 8). In the middle of area there is a region that forbidden for platforms. Each platform knows that rule and when it comes to border that area, otomatically escape from that area. But same time it knows its own original tasks (searching for this example) and finds new path to reach its search area. For that reason, Platform 2 follows sharp path, but Platform 1 follows smooth path. Because, Platform 1 has no overlap with with forbidden zone but Platform 2 has.

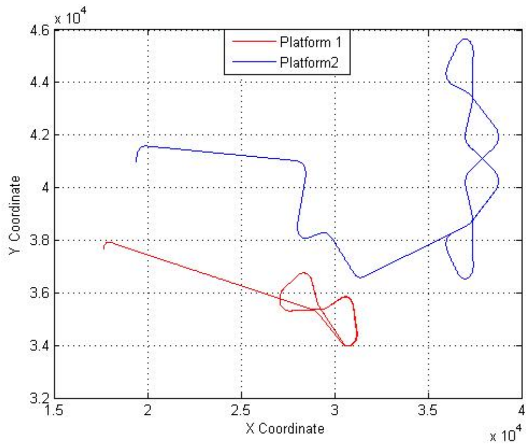

Figure 8 - Search algorithm behaviour for 2 different platforms

In Figure 9, there are 2 different platform that given engagement task. In normal situation platforms have an engagement mission pattern. They first move to related path and then they follow a pattern as shown in figure. As we mentioned before they are convoy members and they have communication with leader. Leader have ability to give orders them any time in simulation. In this example we see that Platform 1 leaves from its original path, attack target (shown as diamond) and then come back to his original path again.

Convoys have common information that shared among members. In this example, convoy has no sensor detection in the beginning of simulation. After some time someone in convoy detected a target and shared in information pool (sensor fusion). Now, all convoy know where target is detected. Leader might give most suitable members to attack. So it attacks the target (Platform 1 in figure).

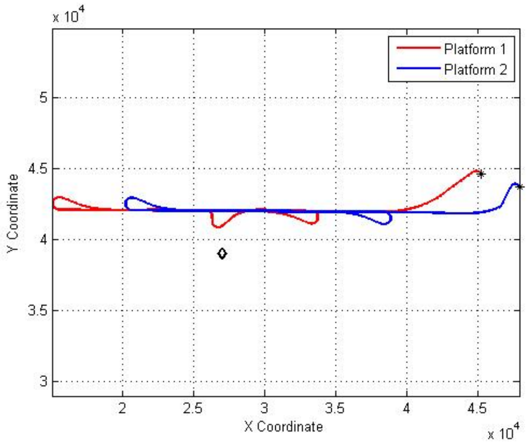

Figure 9 – Engage algorithm behavior for 2 different platforms

Initially platforms have 0 speed. Until reaching the related path, they increase their speed to max and then decarease the pattern speed. Except turning bahaviours they follow the pattern speed. But, as shown in Figure 10. Platform 1 has increased its speed to max again because of attacker phase. After attacker phase it sets its own pattern speed.

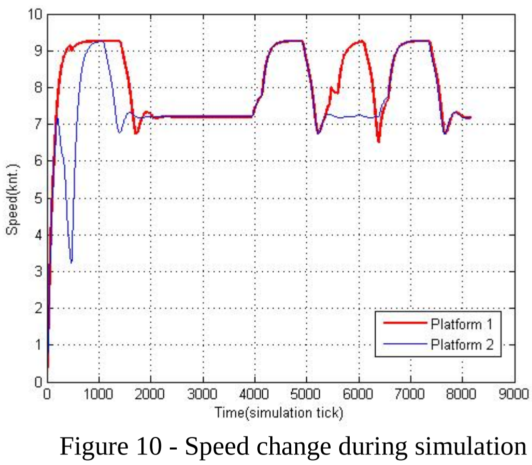

Figure 10 - Speed change during simulation

7. CONCLUSION

In this paper, we explained our training based simulation architecture and Anti-Submarine Warfare concept. We explained in detail our software design about ASW. We illustrate some simulation results about our work.

The whole design is integrated into the component architecture of VRForces, which provides a framework for developing Computer Generated Forces (CGF) applications. Also, commercial toolkit independent simulation components that specialize on algorithmic behaviors are integrated into the commercial toolkit based CGF and GUI applications via developing original control architecture.

There are lots of task that platforms have ability to perform. While performing their original task, they perform some reflexive behaviors such as land avoidance, collision avoidance and step aside maneuver. Our results represent that all single and convoy task successfully achieved as high fidelity.

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SIMULATING THE MARINE DOMAIN AS AN EXTENDED FRAMEWORK FOR JOINT COLLABORATION AND COMPETITION AMONG AUTONOMOUS SYSTEMS

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ABSTRACT
The paper presents the objective and characteristics of an integrated architecture devoted to develop a new generation of simulators able to reproduce joint interoperability among Autonomous Systems over the marine domain. The authors analyze the requirements for such simulation solution in order to address the needs of the applicative context considering different needs: engineering, operations, training and supervision. The paper proposes the general architecture and an approach for integrating different models within this federation; the description of the mission environment is proposed as test case, as well as the preliminary activities for validating these concepts as well as the simulation architecture.

1 . INTRODUCTION
This research aims at developing conceptual models and simulators devoted to support the definition of technical and operational requirements for developing a new generation of interoperable UAS (Unmanned Autonomous Systems) operating over the different domains (Air, Sea Surface, Underwater, Land). The result of this activity is expected to be an HLA Federation that will allow to conduct virtual tests of new UAS configurations and to examine the interoperability related requirements in order to obtain a robust solution able to satisfy mission requirements. Indeed the UAS need to embed and implement interoperability principles to be able to act as a system of systems; currently UAV (Unmanned Aerial Vehicles) are quite advanced in this form, while the operational use of UGV (Unmanned Ground Vehicles) is still quite limited and AUV (Autonomous Underwater Vehicles) and USV (Unmanned Surface Vehicles) are in development phase.
Therefore it is crucial to proceed in this direction to guarantee operational interoperability; indeed this approach will be a support for AxS (Autonomous Surface, Underwater or Aerial Systems) operating for long periods and on multiple tasks over different areas. This paper focuses on operational scenarios running over the Maritime Extended Framework that

includes Sea (surface and underwater), air, coastal areas, cyberspace and space; the paper pays special attention to modeling USV, AUV and UAV interacting with traditional assets over a coastal scenario for multiple operations, for instance intelligence surveillance and reconnaissance (ISR). In this context USV and AUV could drastically increase their capability through interoperability among their selves and with other traditional assets with examples in the interaction among Autonomous surface and underwater Vehicles (AxV in Nad et al. 2011); indeed it is evident the potential of considering them as resource able to interoperate with submarines, vessels, aircrafts, underwater docking stations etc.

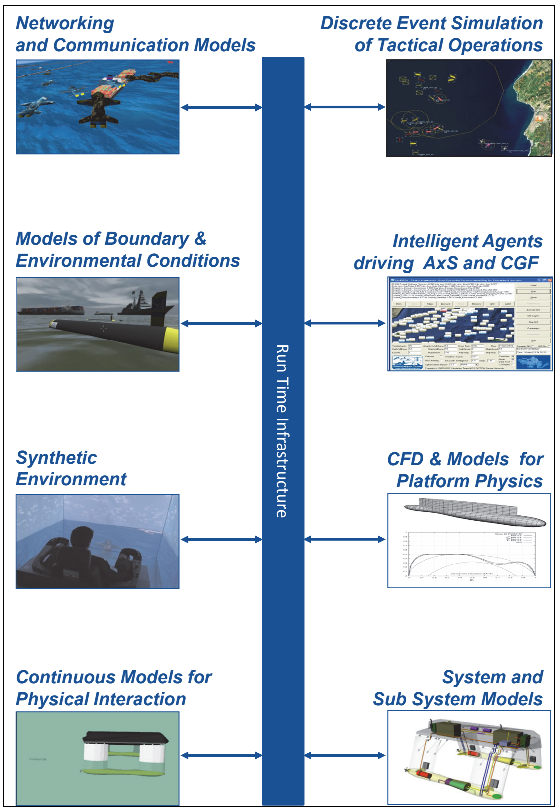

Figure 1: SEAVIT Federation architecture including different federates

2 . OPERATIONAL INTEROPERABILITY AND SIMULATION: SEAVIT FEDERATION

The goal of this research is to create a simulation framework to virtually experiment new interoperable AUVs, USVs and UAVs in order to measure the effectiveness of their interactions with other systems. Indeed the different kind of autonomous vehicles are currently characterized by improvements in capabilities, missions.

This evolution introduces the opportunity to assign more sophisticated roles to AxSs and to pass from single system task to multi system cooperation as well as to collaborative missions. At the same time it results evident the opportunity to investigate the capabilities of AxSs in terms of addressing competitive roles: indeed these systems have already kinetic capabilities (i.e. Reapers and Predators with Hellfire as Unmanned Combad Aerial Vehicles).

Therefore in the future these capabilities are expected to increase as well as to provide the AxSs with systems able to direct not-kinetic actions against opposite forces (i.e. cyber-attacks).

These aspects confirm the opportunity to use AxSs for contrasting and engaging opposite drones as part of a system of systems and the necessity to start investigation in these swarm combat scenarios by using modeling and simulation. In general, considering all the above mentioned elements, operational scenarios are evolving requiring to address AxS interoperability for improving their capabilities and extending their missions to new areas; obviously simulation is the crucial technology also for investigating in advance the alternative configurations, requirements, polices and doctrines related to these phenomena (Bruzzone et al. 2005).

This objective implies that many aspects need to be investigated, such as operational efficiency, costs, reliability, resilience and readiness. Currently the authors are working to create an innovative simulation environment for capability assessment and to develop the requirements for this new generation of interoperable AxSs.

By this approach it becomes possible to simulate in advance the impact of alternative solutions and standardization approaches considering different platforms and concepts (e.g. compare AUVs deployment from a surface platform or from a submarine).

Since the simulation should address different elements, the High Level Architecture interoperability standards (HLA) is considered by the authors the most appropriate and effective computational solution to adopt (Massei & Tremori 2013); the authors used Object Oriended Design and Analysis approach and creates objects for each entity for being shared among the federates (Zacharewicz et al. 2008;Ramos et al. 1999).

Figure 2: Example of Virtual Framework for Marine Simulation of Scenarios involving use of Autonomous Systems

This architecture allows to combine different models into a federation and to keep it open for further developments including HIL and SIL (hardware and software in the loop); this federation is defined as SEAVIT (Sea Environment for Autonomous Vehicle Interoperability Testing) depicted in figure 1. Physical aspects related to specific elements should be modeled and federated within the SEAVIT federation of simulators: examples are the mechanical simulation of the docking/recovery devices or the simulation of marine inductive recharge solutions for AUV; most of these models will be continuous deterministic models. SEAVIT Federation integrates also different models addressing tactical and operational issues in order to investigate the impact of the different alternative solutions; in this case the models are combined stochastic simulators including discrete event and continuous components (Piera et al. 1996; Zachariewicz 2008). Following this structure, SEAVIT has the capability to simulate multiple AxSs and different platforms operating on selected scenarios (i.e. target, suspicious objects, vessels, support devices etc). Due to the complexity of underwater communication system with respect to other environments it becomes crucial to be able to model also these elements; indeed such systems represent a critical issue to guarantee interoperability of existing systems and operational efficiency.

3 BENEFITS FROM SIMULATION OF MARINE UAS OPERATIONAL INTEROPERABILITY

Autonomous Underwater Vehicles (AUVs) have numerous advantages that, potentially, could make them a suitable solution for many military applications including ports surveillance and protection, mines searching, submarines operations support, etc. However, their current development status suggests that it is time to move towards a new generation of AUVs; such new generation of UAS should have in the interoperability with other systems its major point of force. For this reason, since nowaday's AUVs cannot be considered as fully operational vehicles in real missions. Indeed to deploy the AUV is not simple and in addition there are significant problems related to their recovering and recharging operations, collection of the data recorded, sensors replacement etc. Most of these problems could be addressed through standardization problems able to reduce the UAS interoperability capabilities (sensibly increasing the cost of their use and reducing the operative potentials over long time). As far as the recovering operations are concerned, there are different ways to recover AUVs; however often this is a time consuming and expensive operation; much more should be done to design AUVs that have the capability to be recovered in quickly and in standardized way. Similarly recharging operations should be simplified and standardized in order to increase the AUV availability. The data link used to retrieve the data recorded by the AUVs sensors should be simple and effective as much as possible and the replacement (or the change) of some parts of the UAV (i.e. replacing the actual sensors with new ones) should be done with a minimum effort and time.

As matter of fact, most of the problems of AUVs are related to their "physical" interoperability with other systems including other AUVs and/or USV, but, above all, submarines, vessels, aircrafts, underwater docking stations should be remarkably improved. Solving all the above mentioned problems would transform the idea of UAS: from experimental vehicles (as currently they are) to fully operative vehicles (as potentially they could be). The "physical" interoperability with other entities and the standardization procedures require the definition of new technical and operational requirements. To this end the SEAVIT federation is devoted to support the Simulation Based Design of a new generation of interoperable AUVs and USV.

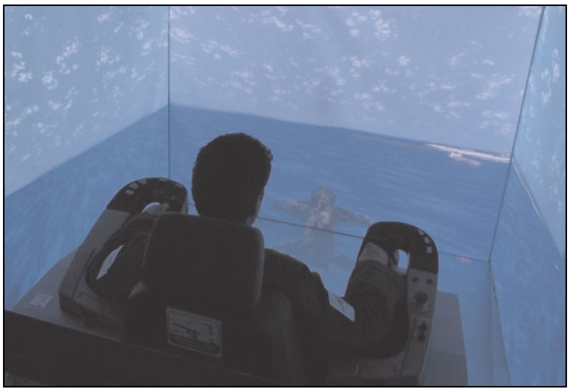

Figure 3: Example of Virtual Manned Cave for directing collaborative Swarms of UAV operating over the Sea

Aspects such us AUS requirements and deployment and recovering methods could be investigated in a safely virtual environment (see figure 2).
Multiple options for recharging operations may be considered in terms of operational efficiency, times and costs. In order to improve the design of the new generation of UAS, SEAVIT environment will provide the possibility to integrate in its HLA federation also real assets and equipment; providing the unquestionable advantage of testing the virtual UAS when interacting with real assets and entities. In addition, the simulation environment will give the possibility to carry out what-if analysis fully supporting and aiding in the design of the new UAS. New standardized components could be tested by simulation without committing resources to their acquisition; at the same time new operating procedures could be explored: i.e. compare AUVs deployment from a surface platform or from a submarine, gaining insight into the importance of those factors and parameters that may significantly affect the performances of the AUVs during their interactions with other entities. To this end the SEAVIT environment will be also able to study and reduce delays and to identify those constraints which pose a limit to the operative use of UAS.
The design of the new AUVs generation would be costly if carried out with real experimentation and prototypes; the SEAVIT environment may strongly support the identification and reduction of risks as well as of the development time. Furthermore the SEAVIT environment may strongly reduce field testing (cost reduction) and supporting – as a consequence – realistic requirements definition, development process and operational testing. In the following some scenario is proposed for applying SEAVIT simulation.

3.1 Collaborative Approach as Enabler for New Capabilities and Performances

The UAS have currently significant limitations on several aspects including autonomy, fire power, resilience and decision making. Some of these aspects could be addressed acting on a single entity design. Collaborative tasks could be improved taking into account the overall performance: from this point of view it is expected that an heterogeneous network of UAS could be assigned to collaborative tasks; in 2012 falls it was possible to complete the Air Refueling, therefore in maritime domain there are several aspects where collaborative assignments could be of interest for being assigned among swarms of UAS and/or mixed group including traditional assets and UAS (Wiedemann 2013); for instance the following actions could improve the performance as well as to introduce new capabilities:

- Joint Patrolling
- Multi Sensor & Multi Platform Data Fusion
- Multi Static Acoustics
- Mobile & Dynamic Heterogeneous Networking
- Command and Control
- Cooperative engagement

In addition to these aspects the following issues are devoted to an operational interaction among similar and/or different UAS or traditional assets such as:

- Deployment
- Refueling and/or Recharging
- Reloading and/or Re-Configuring
- Recovery
-

In particular the above mentioned cooperative tasks are important to enhance the AUV capabilities.

3.2 Autonomous System Competition: New Needs and Concepts To Be Investigated

In the future UAS are expected to assume an active role with a competitive behavior against others drones and/or traditional assets; from this point of view it could be interesting to consider both kinetic actions and not-kinetic activities dealing with

jamming (i.e. Electronic Warfare), Cyber warfare, etc. The competition among drones will require the development of new solutions and systems able to support this activity considering that most of existing weapons and techniques could be neither cost/effective nor able to deal with such targets.
The fight among swarm of drones represents a scenario that could be experienced only by M&S (Modeling and Simulation).

3.3 Examples of Joint Operations over Surface, Underwater and Air within Marine Framework

In the context of maritime extended framework, it is evident the potential to use different drones working on common operations; currently the scenario investigated in this case involves among the others the following assets:

Vessels:
- Frigate and Destroyers
- Patrol Boats
- Cargo Ships
- Submarines

Drones:
- AUV - Underwater Drones
- UAV – Aerial Drones
- USV – Surface Drones
- UGV – Ground Drones

Aircrafts:
- ASW Helicopters
- Patroling Planes

Ground Units
- Coastal Battery
- Company
- HQs

Weapons:
- Torpedos
- Missiles

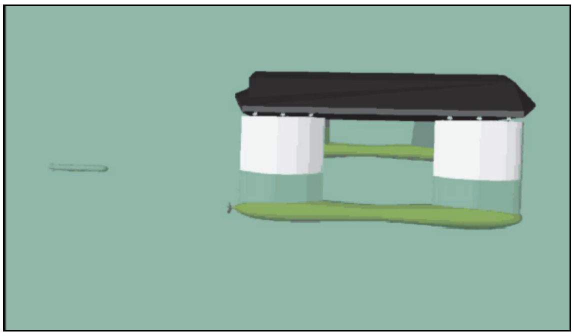

Fig.4 - Model of the AUV approaching the SWATH-USV

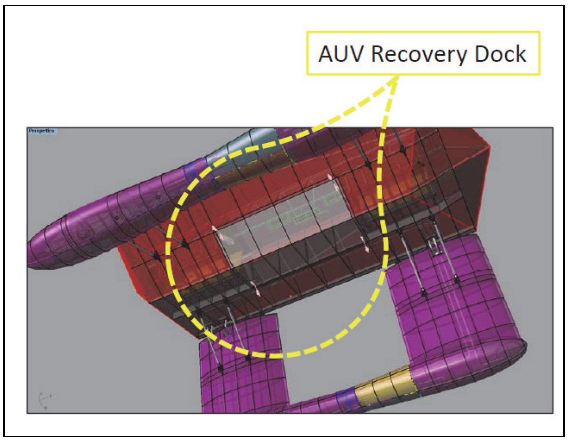

Figure 5: Detailed Model of the AUV Recovery Dock in the USV

Sensors:
- Hydrophones
- Active Sonars
- Sources for Multistatic Acoustics
- Radars
- EO/IR (Electro Optical/Infra Red)

The scenario was developed as ISR operation conducted in hostile waters near the coast; the zone was subjected to commercial and private traffic in some areas while the OPFOR (Opposite Force) involved ASW (antisubmarine warfare) capabilities, sensor networks and infrastructures and defensive drones; in addition in coastal area there are ground units able to activate anti-ship operations. The Blue Forces vice versa operates within the area just through a submarine, multiple AUV, USV and UAV. It is evident that the boundary and environmental conditions (i.e. sea, wind, temperature, fog, etc.) could heavily affect the performance over the same operational scenario and require proper models; it could be interesting in the future to develop integrated representations that could support this approach (Sanz 2008). In the proposed simulator, the USV might have kinetic and not kinetic capabilities, while in this scenario the AUV don't have kinetic weapons, but could produce jamming and other not-kinetic actions; the UAV carry multi sensors and weapons. In comparison with electric drones, the AUV was modeled with capability to communicate in RF in surface and through acoustic modems underwater; vice versa the USV used for this scenario was inspired to SWATH (Small Waterplane Area Twin Hulls) USV characterized by Superior

Operability over wide spectrum of sea states and able to provide support AUV (Brizzolara, Curtin, Bovio, Vernengo 2011; Brizzolara and Vernengo 2011).

Interaction AUV-USV

The simulator is modeling the interactions among AUV and USV; the USV is able to Deploy and Recovery AUV (see figure 4). The USV is also able to carry several AUV; so it becomes interesting to evaluate the dimensions of AUV and USV in terms of storage capability and characteristics (i.e. speed, autonomy, payload, visibility/detectability, etc) as proposed in figure 5. The USV could recover the AUV through an intelligent interactive device and to recharge it; data link is available, while it is possible to set up possibility to change the AUV payload on board. The improvements provided by using USV with capability to recharge the AUV through innovative inductive charging solutions are going to be tested thanks to this simulator. USV are modeled to be source for multistatic acoustics by emitting active pings and supporting fusion with AUV, hence the USV includes models of passive and active sensors and also weapon systems.

3.4 Interaction UAV-USV-AUV

The use of UAV within the heterogeneous network of drones, introduces new interaction capabilities. The model allows to deploy the AUV launched with a parachute; in addition UAV have possibility to reinforce communication and sensor network; these drones could proceed in cooperative targeting and engagement respect USV as well as AUV for ASW.

4. STATE OF ART WITHIN MARINE DOMAIN

The introduction of autonomy within unmanned vehicles creates opportunities for new roles and activities; in particular it becomes necessary to address new complex operational roles involving collaborative and competitive tasks. A great challenge is the involvement of different disciplines, such as computing science, mechatronics, artificial intelligence and to consider the needs for operational interoperability; in addition it will be soon necessary to address in a new way the aspects related to interactions among AxSs and humans moving from traditional direction and driving to high level supervision (Bocca and Longo 2008; Bruzzone et al.2013); these concepts were investigate in several cases and represent a critical issue for UAS research field (Cooke et al.2006) where interesting research are on-going (see figure 3). In addition, a corner stone for succeeding in this sector is the capability to generate some form of applicative intelligence able to direct robot cooperation in complex scenarios (Fernandez et al. 2013). This intelligence will need to be clearly defined by fixing capabilities and features able to measure and verify the ability AxSs (Bruzzone 2010); many techniques could be applied in this sector including IA (Intelligent Agents), AI (Artificial Intelligence), Swarm Intelligence, Fuzzy Logic, Genetic Algorithms, game theory, theoretical biology, distributed computing/control and artificial life; the authors of simulation team obtained interesting results in this sector by combining different techniques (Bruzzone et al. 2008; Zacharewicz 2008; Affenzeller et al. 2009); interesting results in directing collaborative and competitive assets within simulation were achieved by the development of IA-CGF (Bruzzone 2008; Bruzzone 2010 et al.); indeed it is evident the importance to adopt simulation interoperability standards to create frameworks to check a priori the interaction among the different systems and to test prototypes in a virtual scenario (Zini, 2012). Obviously the evolution of the potential scenarios for UAS (unmanned autonomous systems) was investigated along the years (Ross et al. 2006; Tether 2009; DARPA 2012; Lundquist, 2013) addressing a series of projects and examples on a wide spectrum of applications involving different levels of complexity over the different paradigms.

The use of the new generation drone within collaborative competitive mission is evolving as an important research area, therefore the scientific works in literature related to interaction of heterogeneous swarms driven by agents over all domains, such as fleet of UAVs, UGVs, AUVs and SUVs, are fairly limited. However there is an interesting scientific production addressing the problem of developing frameworks for the coordination of multiple vehicles belonging to the same single class: examples are available about multiple UAVs (Vail 2003) and multiple AUVs (Richards et al. 2002; Stilwell et al.2004).

In sea environment it is interesting the research conducted on joint operations involving a single UAV coordinating multiple AUVs while performing oceanic exploration missions (Sujit et al. 2009).

Some of these aspects were already investigated for marine environment creating a multi robot system involving an aerial (UAV), a surface (ASV) and an underwater vehicle (AUV) within the same team (Shkurti et al. 2012).

These research are evolving along the last year to more operational roles; for instance another interesting case of collaboration is related to MCM (mine countermeasures) and it was investigating the collaborative use of an AUV and an autonomous kayak (USV) (Shafer et al. 2008); another in case related to detection and targeting in hostile environments it was studied by coordinating ground and aerial unmanned vehicles (Tanner 2007).

Scalability and Flexibility are major aspects to be investigated in these applications to support future mission environments; these aspects were addressed in relation to detection and tracking of unknown forces by using UAS over air and ground domains as well as a network of low cost sensors (Grocholsky et al. 2006); in this field there is also another example where two groups of mobile agents (UGVs and UAVs) were simulated to estimate their potential in terms of intelligence surveillance and reconnaissance (ISR) missions (Tanner et al.2007).

Studies related to the cooperation among different kinds of UAV and AUV over a port environment for security were investigated by using interoperable HLA Simulation (Tremori, Fancello 2010). An effective approach has been followed by Simulation Team; namely a stochastic simulator of joint operations involving UAV and other assets such as ground units, attack helicopters and planes, called IA-CGF U-COIN (Intelligence Agent Computer Generated Forces UAV and Counter-Insurgency) (Bruzzone et al. 2010).

5. MODELING & EXPERIMENTATION

The SEAVIT architecture is designed in order to be open; so it becomes possible in the future to federate and to simulate real assets (i.e. aircrafts, vessels, submarines, ground units, satellites, HQs) interacting with virtual ones creating a live, virtual and constructive framework addressing the whole problem.

In general, these different models and elements are expected to become part of the same simulation framework and the SEAVIT Federation will allows to estimate metrics through application of design of experiments (DOE) in order to identify most influent design parameters and most effective operative alternatives for maximizing the overall performance (Montgomery 2000; Andronov & Merkuryev 2000; Longo et al. 2012). The study is expected be conducted applying design of experiments (DOE) over a complex scenario affected by stochastic elements (i.e. detection probability, false alarms, kill probability, etc.).

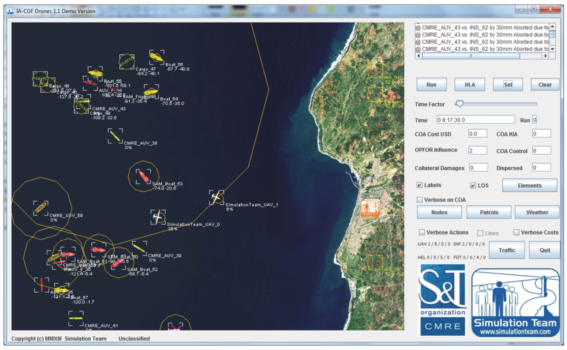

Figure 6: Tactical interoperable Simulation including AUV, USV and UAV as well as conventional platforms in the SEAVIT Federation

In fact the SEAVIT main goal is to investigate requirements and solutions to be adopted for Interoperability of Autonomous Underwater Vehicles; this goal should be achieved by creating a simulation framework able to carry out experimental analysis at "virtual sea" for supporting design and re-engineering.

The advantage of the proposed approach is the possibility to conduct tests over complex scenarios including operational issues and specific environmental conditions with a large number of assets and UAS; following this approach the configuration and alternative solutions are evaluated in the virtual environment under stressing characteristics and in reference to their interactions with other assets in ways that are impossible to reproduce during live exercise at sea or could not be applicable during design phase of new AUVs that are not yet existing.

SEAVIT Federation will address the verification and validation processes for this case and the architecture description in order to enable the possibility to federate in this system.

Even if AUVs are a specific narrow niche, their interoperability will be a real breakthrough advance extending opportunity of use, increasing the number of applications and the quantities of available devices. This will bring opportunities for new designs and re-engineering processes as well as for further developments.

6. SEAVIT FEDERATION DEVELOPMENT PHASES

This paper is introducing the modeling approach and initial design phase of SEAVIT Federation; indeed the SEAVIT federation is organized in three major phases; the initial activity focuses on identifying all the main issues related to AxSs requirements engineering and operative scenarios as well as to define the operative and performance metrics and critical parameters to be used to re-engineer the requirements during the simulation; this phase is especially focused on AUV and their interaction with USV.

Some specific scenarios need to be identified to develop an initial configuration of the SEAVIT Federation able to demonstrate the potentials of this approach; obviously it is also necessary to define verification and validation processes of the simulation framework by providing a first set of design criteria and operative evaluations for the virtual experimentation.

The second phase aims at providing details for the conceptual design of SEAVIT models and of SEAVIT federation. To this end, the HLA standard for interoperable simulation enable the integration of new models as well as the adoption of legacy systems (if required existing models). The authors are currently designing the federation for an extensive use of IA-CGF (Intelligent Agent Computer Generated Forces) integrated within the SEAVIT federation in order to reproduce the intelligent behavior of autonomous systems as well as traditional assets.

In addition, in the future, the SEAVIT Federation could include also HIL and SIL, MIL (man in the loop) as well as real assets and systems.

The last phase of this research is expected to focus on the implementation of SEAVIT Federation and in its extensive experimentation; this allow to experience in a virtual environment the effects of different alternatives for AxS configurations, with special attention to operational interoperability requirements; by this approach it could be possible to quantify for each solution the costs/benefits ratio.

As additional results, SEAVIT federation is expected to provide a summary of the experimental results about interoperability and operative issues affecting new AUVs, USVs generations. The SEAVIT federation represents an innovative resource for identification of operational interoperability requirements and for developing new solutions for an operative use of AxSs as standard interoperable elements operating on field side by side with traditional assets.

Furthermore the SEAVIT federation demonstrator could be available for further extensions and for analyzing additional issues and new scenarios.

7. GENERAL ARCHITECTURE PROPOSED

SEAVIT is an interoperable simulation based on HLA (High Level Architecture) able to run in different configuration combining both detailed models for engineering as well simplified meta models for real-time and fast time simulation devoted to support capability assessment and eventually in future training. The general architecture is proposed in figure 1.

SEAVIT models are stochastic considering the influence of several important factors (i.e. probability to detect, probability to hit, probability to kill, operation durations, mean time between failures, etc). Among the federates it was possible to identify the following models:

- Discrete Event Simulation of Tactical Operations
- Intelligent Agents driving AxS and CGF
- Models of Boundary & Environmental Conditions
- Networking and Communication Models
- CFD & Models for Platform Physics
- System and Sub System Models
- Continuous Models for Physical Interaction
- Synthetic Environment

7.1 Different Interoperable Models

The interaction among the different models should be defined in SEAVIT federation in order to address specific simulation goals; in fact the computational models devoted to reproduce system physics (i.e. Computational Fluid Dynamics, Partial Differential Equations) are important to address single platform performance and details about their interactions.

Therefore the discrete event simulation and the intelligent agents represent the corner stone to run complex scenarios and to evaluate at high level the operations, doctrines and policies as well as the overall characteristics and configuration of different drones. By this approach it becomes possible to analyze different hypotheses about the drones and the operations as well as the most effective characteristics to address a specific mission environment.

Synthetic models could be effective in proposing the results of the simulation both for Verification and Validation as well as to present to user the different solutions and their operational modes.

All these models and simulator should be developed in consistency with HLA standard in order to be interoperable, so it becomes possible to couple a detailed physical model with a constructive simulator as well as with a communication network simulator; therefore it is evident that these models could be characterized by different time characteristics.

The authors are currently planning to develop SEAVIT by adopting conservative time management, so it means that when a slow time simulator is joining the federation all the processes slow down; for this reason it is important to develop simplified meta-models able to approximate the models within a well-defined analysis range; so it becomes possible to run fast time simulators by substituting the detailed federates by meta models and to conduct the experimental analysis by applying DOE over a large number of experimental runs; therefore when the best solution is identified it is possible to run back the simulation including detailed models to test and verify that configuration; in this way the approach guarantee maximal flexibility and efficiency at once.

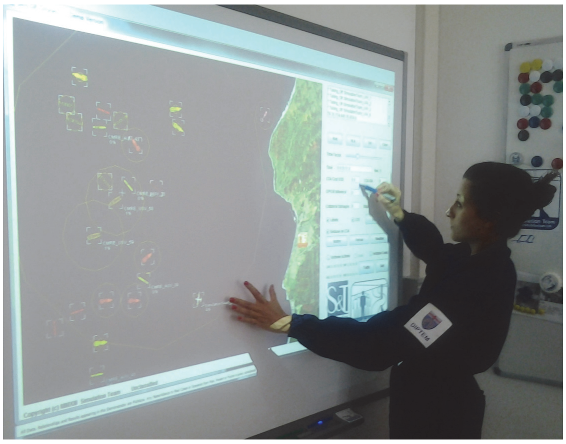

Figure 7: Testing and Experimentation of the SEAVIT Federation in DIME University of Genoa M&S Labs

7.2 Network Issues for SEAVIT Federation

Future concepts for network-enabled systems will involve the operation of mobile ad hoc networks to enable the integration of heterogeneous Autonomous systems with larger scale networks and Command and Control (C2) systems. The need of providing self-configuration, to handle dynamic topology changes in the absence of pre-deployed infrastructures, clashes against the practical difficulties of communicating in the maritime and underwater domains. The main challenge follows the fact that radio propagation is severely impaired underwater, leaving acoustic communication as the foundational technology to interconnect Autonomous Systems operating below the sea surface. Propagation of sound in the water occurs with a speed that is five orders or magnitude slower than above-water RF (1.5 x 10^3 m/s versus 3 x 10^8 m/s) in a time-varying bandwidth-limited channel that is severely impacted by environmental conditions and subject to frequent disruptions. Additional constraints derive from the fact that vehicles are exposed to the risk of being detected, captured and compromised. Threats against confidentiality, integrity and availability, such as denial of service, node displacement, false data injection, have to be countered using limited resources on battery-powered platforms. In addition to that, information exchange processes are normally served using shared/public communications media, which translate in exposure to passive and active attacks, such as eavesdropping and jamming. To make things more complicated, failures and manumissions could remain unnoticed, especially where connectivity between control centre and vehicles are intermittent.

The delivery of a joint interoperable framework for Autonomous Systems in the marine Domain drives therefore the need of encompassing several integrated elements, such as vehicle-to-vehicle communication using acoustic media (or radio, for surface operations), vehicle-to-C2 communication using satellite communications (for command and control and telemetry), data messaging standards (to enable interoperability with existing capabilities that consume data produced by autonomous systems deployed in the field), and cyber-security, as a cross-cutting component of all the above-mentioned sub-systems. Simulation approaches, essential to support the development and evolution of such complex capabilities, need to be founded on reasonable representations of the challenging environment in

which the agents will be called to cooperate (or compete), This could be tackled from different complementary approaches, ranging from accurate modeling of, e.g. acoustic propagation, taking into account environmental factors such as bathymetry, water column temperature, salinity, etc., to higher level synthetic models providing a compact representation of system states, where network-enabled systems can deliver their function only when the networking function is capable of operating as needed: failures in communication due to environmental factor or hostile activities such as cyber-attacks will have an adverse impact on the whole of the application that has to be delivered.
Eventually, Monte-Carlo approaches could be envisioned as the best mathematical tool to run experimental analysis. everal agents, representing collaborating and competitive autonomous vehicles, are operated in the context of a pre-defined scenario, to include the networking sub-systems, to gather useful statistics on overall system effectiveness and resiliency. Those statistics could be further analyzed with data farming techniques to identify the key parameters that need to be controlled in order to maximize system performance.

7.3 SEAVIT Execution and Experimentation

The proposed scenario related to ISR over a coastal area where drones are collaborating to complete their mission in a hostile environment where OPFOR are acting with traditional assets and other drones. The scenario was tested over a Mediterranean environment and several experimental runs were conducted using simplified meta-models for detection and directly tracking integrated within the Discrete event tactical interoperable stochastic simulation; the UAS as well as traditional assets were driven by IA-CGF derived from IA-CGF UCOIN previous simulator. The simulator is currently involved in dynamic, statistical and integration testing as presented in figure 7.

8. CONCLUSIONS

This paper presents the initial study for the development of a new federation related to AxS involved in collaborative and competitive missions; indeed in this paper it is proposed the definition of objectives, architecture and general configuration for this innovative Federation, titled SEAVIT, that addresses the creation of an interoperable stochastic simulation able to analyze requirements of future UAS. The focus on marine environment and ISR mission, allowed the authors to define bounds for such federation and the Models' characteristics needed to conduct preliminary tests and to verify and validate the approach: it has clearly emerged the importance to use interoperable agents as driver of the objects and entities.
Currently the federation development is in initial phase and it is expected to be extended in next year.
Therefore it is important to outline that this research initiative is an opportunity to create a trans-disciplinary team for autonomous system simulation involving people from Institutions, Academia and Companies that interact with final users and subject matter experts. So SEAVIT federation will enhance the possibility to create a pool of people and institutions with proved experience in the strategic sector of the new generation interoperable UAS. The project team, with strong modeling, simulation and engineering capabilities and a soundly technical background, will enable virtual experimentation and the investigation of new concepts, solutions and policies within complex and realistic mission environments over the maritime extended framework.

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3D TERRESTRIAL LASER SCANNER USED TO REPLICATE A REAL MILITARY VEHICLE SUITABLE TO CONDUCT STATIC AND DYNAMIC TESTS IN A VIRTUAL SCENARIO

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ABSTRACT
The aim of this paper is to provide the reader with an accurate description of all the steps and procedures needed to use a Laser Scanner as suitable tool for creating 3D models from real objects/environments. By following the steps and procedures described in the paper it is possible to carry out a physical survey of the object being modeled, create a mapping assessment in term of object measurement, execute in a simple and quick way the scanning activity (also in a limited time), use the 3D model for Virtual and Constructive simulations.

Keywords: 3D Models, Laser Scanner, Virtual Simulation, Military applications.

1. INTRODUCTION
With the more and more technology available in the field of Modeling & Simulation, a Laser Scanner enables users to recreate (with high accuracy) 3D models of real objects and/or environments. Such a result allows using 3D models in Virtual and Constructive simulation with the aim of carrying out what-if analysis as well as supporting simulation based design and systems acquisition.

Objects are replicated with very high accuracy (i.e. less than 1 mm error rate from 120 m detection point) and then they can be placed into simulated scenarios. Nowadays Laser Scanner is versatile and user friendly tool which aim at reaching a good trade-off between the accuracy of the 3D models and their appearance as part of the simulated scenarios. This is got through pictures taken by the camera working with the Laser Scanner. As explained throughout the paper the procedure to get the final result is simple and fast with the engagement of very few operators. The application example presented in this paper is related to the creation of military armored vehicle called "Freccia" from the Italian Army conducted through a 3D Terrestrial Laser, property of NATO Modelling & Simulation Centre of Excellence in Rome. The overall dimensions of the vehicle are 8,6 m in length, 2,9 m in width and 3 m in height.

As any military vehicle, the Freccia vehicle is quite complex and includes a number of relevant structures and components that need to be perfectly replicated in order to provide the user with the sensation (during the virtual simulation) to deal with a real military vehicle. The scanning activity has been conducted in two phases:

- 1st phase: on the field to scan the real vehicle using also a mobile pad to bounce off any surface of the vehicle. It lasted three hours with two operators;
- 2nd phase: data processing conducted at home. It lasted six hours with two operators.

By following this approach it is also possible to create libraries of 3D models to be used in different simulation models (the 3D models can be then easily exported in different file formats and therefore imported by many 3D CAD tools).

2. RELATED WORKS
A brief survey of the current state of the art, clearly reveals that the 3D Terrestrial Laser Scanner has been used for different purposes and applications. As follows a review of some references is reported to provide evidence on the relevance of the proposed approach.

Indeed the 3D Terrestrial Laser Scanner is not only used in the Military Sector but also in other relevant sectors including Archaeology, Environment, Geology, Industry and Defense.

3D laser scanning has been applied in cultural heritage conservation and civil engineering applications succesfully (Abmayr et al. 2005) Moreover in the field of cultural heritage, terrestrial laser scanning has been integrated with photogrammetry and thermal imagery in order to record accurate and exhaustive information about World Heritage Monument (Rönnholm et al. 2007). Nguyen et al. (2012) use the 3D laser scanner to create 3D models of real monuments, historical buildings, churches; the results of the paper clearly show how the method proposed by authors can effectively and quickly used to reconstruct 3D object geometry with many details (for cultural/archaeological heritage purposes).

In a modeling and Simulation oriented perspective 3D laser scanning has proved to be a valuable support for generating geometrically correct and complete 3D models of objects and environments (El-Hakim, 2000).

To this end Sequeira et al. (1999) propose an integrated approach aimed at developing textured 3D scene of building interiors from laser range data and visual images. As a result this approach leads to reality models that could be applied in a wide range of virtual reality driven tools.

Indeed, creating 3D models of real world scenarios is an important research topic and may have applications in many others areas such as Industry and Defense. The main challenges in this research field include the acquisition of large-scale data, the complexity of the scenarios under investigation and eventually the difficulties to cope with variations in the scenes resolution in order to reduce the computational workload (Matos et al. 2004). To this end, even if advanced commercial solutions are available, their prices are not affordable therefore researchers have often proposed alternative techniques (i.e. Dias et al., 2004 propose a 3D reconstruction technique for real world environments based on a traditional 2D laser range finder modified to implement a 3D laser scanner). Moreover Bornaz et al. (2002) propose a fully automatic software that makes use of laser scanner data for engineering and environmental applications. In this area Bellian et al. (2005) explain the work-flow to use the 3D laser scanner for geology purposes and discuss the construction of rock-based 3D Digital Outcrop Models. In addition Lkeuchi (2001) introduces the modeling-from-reality (MFR) project whose goal was to develop techniques for modeling real objects and/or environments into geometric and photometric models through computer vision techniques. In general, this brief state of the art overview reveals that 3D laser scanning applications can drastically shorten the developing time of virtual scenarios usually time-consuming and undertaken by Human programmers thus a greater level of automation allows reducing developing costs.

At NATO MSCOE there are some ongoing researches that see the use of the laser scanner for creating 3D models to be integrated within Hybrid Worlds for Multi Robot Cooperation (the first presentation of the above mentioned activities was made at ITEC 2013, in Rome). In addition other NATO research centers (i.e. the NATO Centre for Maritime Research & Experimentation) are using the Laser Scanners for tests related to the control awareness of threats coming from the sea, for simulation based acquisition prototype systems (to avoid not appropriate investments or commitments with industries), for civil protection purposes to monitor landslides.

As clearly explained in Bruzzone and Longo (2010), and Bruzzone et al. (2011) one of the major issues in creating 3D models for Virtual Simulation is the trade-off between the appearance of the 3D model within the Virtual Environment and the workload of the computer graphic card. A real object such as a military vehicle contains thousands of faces (modeled as triangles); faces are then mapped with textures in order to have a realistic representation. Consequently, the computational effort could easily exceed the graphics card capabilities of a low-cost hardware platform. To avoid computational overload, high-resolution and low-resolution graphic detail levels must be implemented. The levels are activated (activating one excludes the other) according to whether the observer is close to or far from the object being observed. Bounding boxes define the portions of space – within which the vehicle of interest is located – whose confines, if crossed by the observer from inside to outside, lead to a switch from one high-resolution texture to one low-resolution texture.

3. ABOUT 3D LASER SCANNER

The 3D Laser Scanner bounces its laser rays off the surfaces of the objects to be scanned. The return of the rays provides the position of the point captured. The main part of a Laser Scanner consists of a main body connected with a special mirror able to provide millions of measurements in few seconds (according to the model of the Scanner, the desired definition and quality). The output is a Points Cloud into a coordinate system SOCS (Scanner's Own Coordinate System) related to the instrument and survey station (initially spherical polar coordinates which are then translated into Cartesian coordinates). To each of these points it is also associated the intensity factor (phase variation or Laser Scanner color).

Figure 1 shows the 3D Laser Scanner owned by NATO M&S COE. There are two different typologies of Laser Scanner:

- Time of Flight Laser Scanner: this specific Scanner sends out a laser impulse which is bounced back from the object. A sensor measures the time taken to receive back such impulse. Since the speed of Laser ray is known (Speed of Light in air) the distance is then easily calculated.

Figure 1: 3D Terrestrial laser scanner at NATO M&S COE

- Phase Shift Laser Scanner: in this case, when calculating the distance, the "Time of Flight" also takes into consideration the shift of phase between the ray sent out and the one received back. This kind of measurement is more accurately executed if compared to the one given by time of flight Scanner, but the radius of action of the tool is reduced significantly.

The 3D Terrestrial laser scanner type LIDAR (Ligth Detection and Ranging) used for the application example proposed in this paper is a 3D Terrestrial Phase Shift Laser Scanner security class 1. Figure 2 depicts a schematic representation that shows how the 3D Laser scanner works.

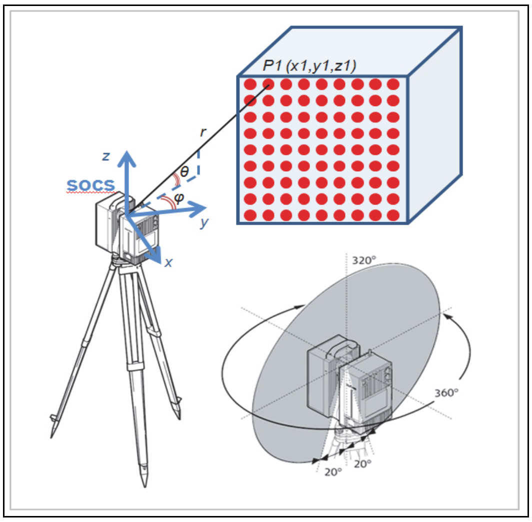

Figure 2: Schematic Representation of the idea behind the 3D Laser Scanner way of working

The result of the laser scan activity is the object replicated through millions of points each of those processed by the 3D Terrestrial laser scanner with space references (x,y,z) and intensity factor (I). All data is stored inside the machine and the output is represented as a points cloud.

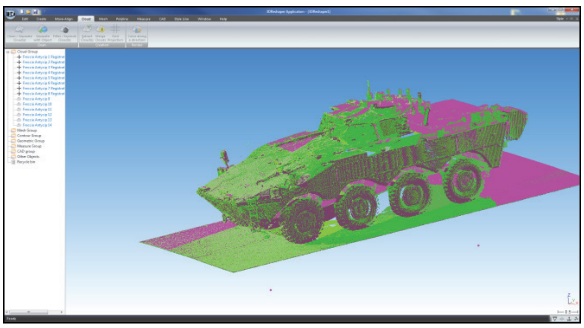
Figure 3: The points Cloud of the Freccia Vehicle

The fully loaded weight of the Laser Scanner is only of 12 Kg and it is easily transportable; its setup is also simple to execute. It is placed on a tripod in parallel with the floor. A bubble level helps to do this manually for the roughly phase. The final phase is executed automatically which is a due operation before starting with the activity. The scannering of the object is also completely automatic and it can be carried out in the night as well or with scarce luminosity. In addition, it is possible to give geo references to the cloud of points detected by the Global Navigation Satellite System (GNSS). What is very important to take into account is:

- The Laser Scanner detects data only from the surfaces in its sight (320° V, 360° H, like cone field of view). For this reason the scannering implies more than one point where we detect from, taking into account the shape of the object itself and making available superimposing of pictures. This is needed in the post-processing phase for linking all clouds without any gaps in images.
- It is needed to operate inside the radius of action of the machine according to the model we are working with (the one used for the specific activity has 180 range). The more you walk further from the object the less accuracy you get;
- Different surfaces have different reflections. Some of them can even absorb the ray or send it back distorted (glasses, water surface, mirror). This is way it is required to assess the best position where to detect from. The last factor to take into account is also the angle of incidence for the object detected.

4. THE "FRECCIA" FIGHTING VEHICLE 3D MODEL

The real word object that we take into consideration in this case study is the "Veicolo Blindato Medio Freccia" 8×8 infantry fighting vehicle (IFV).

This is a medium armoured vehicle developed by the consortium Iveco-Oto Melara. It is the first digitized vehicle to enter into service with the Italian Army. The IFV overall dimensions are the following: length: 8.6 m, width 2.9 m, height 3 m, weight 26 tons. The IFV hull and turret are aluminum with a layer of ballistic steel fitted to provide higher protection. The armored personal carrier can carry a crew from three to eight soldiers. It is fitted with a Hitfist Plus turret with an Oerlikon KBA 25mm automatic cannon(in prototype model) a pointing laser device and a thermal night camera.


Figure 4: The 8×8 infantry fighting vehicle (IFV)

The decision to carry out the activity on the military vehicle has been made for the following peculiarities:

- complex shape of the vehicle;
- short time available since the object has a real operational role in the Unit for training purposes;
- all real details are available on a real object rather than on a scale drawing. If a drawing had been used a longer time would have been necessary.

In the post-processing phase the Modelling of a 3D object by a 3D Laser Scanner can be integrated by an hand-made work on specific piece of surface, especially if we deal with simple geometrical shapes as parallelepiped for a building or a cylinder to replicate circle shapes. The aim of this activity had to meet two requirements:

- to get a very detailed object in order to give to operators of the vehicle in training phase the opportunity to survey the object which had the highest level of fidelity;
- to add the object into virtual or constructive simulated scenario easy to interact with.

The requirements below have been met, in particular:

- the high resolution of the detection and the very low rate of error (< 1 mm.) has been a outstanding achievement (static survey);
- the chance to import the object in a dynamic scenario by a software called "Scenario Generator Animator", is given by excluding unnecessary details of the vehicle to make it light to play it dynamically.
- The same data after the detection activity has been elaborated to get two 3D models of the same object:, one for static use and one for dynamic use. The step to move from the first one (more detailed) to the other, has been possible by software tools available at the NATO M&S COE Center.

5. 3D MODEL PROCESS RECONSTRUCTION

The following part of the paper describes the procedure and steps followed to create the 3D model of the IFV; in particular there are four main steps:

- Data Acquisition
- Noise Reduction and cloud cleaning
- Registration Process
- Texturing operations

5.1. Data acquisition

In order to create to acquire the data to create the 3D Model of the IFV, the Laser Scanner has been used with the Leica Geosystem HD-S /7000 by operating 9 scanning through the object from different positions with "High Density" resolution (with a point spacing at 10 m of 6.3 mm) and " High Quality" as setup of the Laser. This activities has taken us 3 hours and has involved 2 operators.

Figure 5 – A view of the IFV during scanning operations

Figure 6 – An operator working on the laser scanner during the acquisition process

Pictures have been taken simultaneously by a Camera NIKON, reflex mod. D 7000 equiped with a view finder Nikon fisheye 10.5 mm. Pictures will be used as textures linked to the cloud of points to obtain a realistic representation of the IFV. Other pictures have also been taken by the same camera, but with a view finder 50 mm. All data of 9 scans with pictures has been transferred to a workstation to proceed with data elaboration by using the Cyclone version 8.0 software.

5.2. Noise Reduction and cloud cleaning

Before using data the "cleaning of the noise is required. To this end we remove manually what is not necessary from the cloud. We take into consideration that everything which is in the FOV (field of view) during our scanning is captured by the laser scanner. Thus what is not part of the object must be deleted. The following step was to filter automatically all data by SW Cyclone which operates also on those points due to the multipath reflection.

5.3. Registration Process

The registration process operation has the purpose to bring back to a single reference system all the points clouds of the (single) respective scans. Transformation between different coordinate systems, once defined the coordinate system of a station S1 as the reference of the project turns out to be a rigid transformation including rotation and translation in space for all the K stations carried during scan activity.

This process transfers all cycles of scanning to the same coordinate systems with the aim of linking the several clouds all together. Note that some "targets" are needed during the scanning activity; these targets are some recognized points in the environment where the object is placed. It is important to have at least three common targets for each contiguous scanning to make sure to have the exact coordinates to be registered in the main system.

The registration phase has been operated by using the software Cyclone. Having significant number of contiguous scanning (in our case 9 scannings) and using the "targets", we were able to link the different points clouds through a multi station adjustment (MSA) function (in order to minimize the error of alignment).

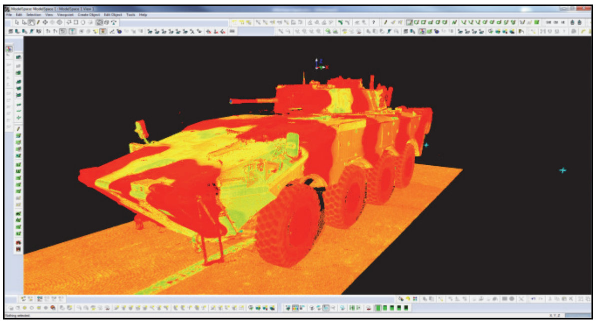

Figure 7 – the 3D Model of the IFV resulting from linking the 9 points clouds

The result of the linking of all "clouds" is the Vehicle Freccia represented in its real dimensions (error rate < 1 mm.), at the appropriate resolution for a 3D static model.

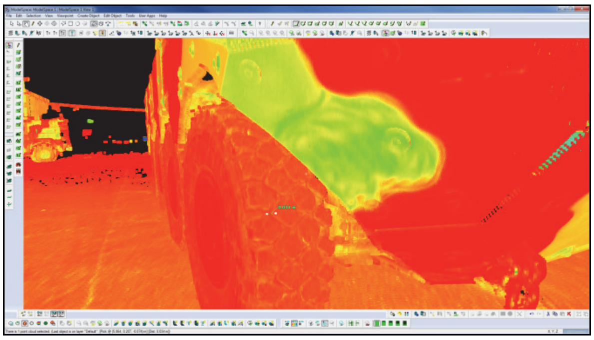

Figure 7 – A view of the IFV wheel

While the registration process allows recreating the 3D Model of the IFV, the model still miss a realistic representation that can be obtained by carrying out the texturing operations as described in the next section.

5.4. Texturing operations

To complete the work, we carry out some texturing operations on the clouds. The pictures taken during the acquisition phase, have been processed by the software tool PTGUI vers. 9.1.3 which transforms them into cubic equirectangular, suitable format to be textured onto the clouds. Only at this step we can have the IFV vehicle available for static survey (see figure 8).

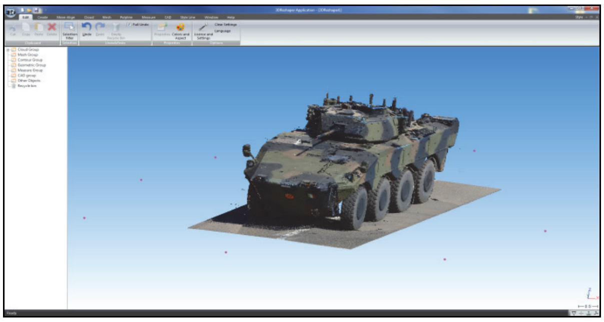

Figure 8 – The IFV 3D Model after Texturing operations

You can make such a model available (on line or intranet/internet) by the software Cyclone browsing on Internet Explorer or use the free plug-in TrueView that allow you surfacing the object as well as perform measurements (see fig. 9).

6. 3D MODEL REPLICA OF VEHICLE FRECCIA FOR VIRTUAL/CONSTRUCTIVE SCENARIO

The goal of this paragraph is to outline the process to replicate the same Vehicle also for dynamic use given the cloud from the 3 D Laser Scanner. The authors have a remarkable experience in developing Virtual and Constructive simulation models in different areas, including Defense (Bruzzone et al., 2011; Longo 2012); Tremori et al., 2009), Industry (Longo et al. 2012) and Logistics (Bruzzone and Longo, 2013).

Fig 9 IFV 3D Model used for static survey

6.1. 3D DATA MODELLING

The process of Data Modeling is the step required to replicate a 3D Model (in this case the IFV) for dynamic use in simulated scenarios. To make the IFV 3D model available for use in virtual/constructive simulated scenario, it is necessary to build the model as made by continuous surfaces. The cloud data has to be converted into a polygonal surface through a triangulation called Mesh representing the discrete surface of the scanned surface.

To do this the software tool 3D Reshaper ver. 7.1.2. has been used. Through appropriate algorithms (reconstruction algorithms), the cloud has being transformed combining the closest points and calculates some new ones, making up surfaces interconnected each other. The process provides a 3D model of the object consisting of a triangles linked each other (see figure10). In this phase additional activities to finish off the work might be necessary if we have some defects due to the reconstruction algorithms mentioned above. These activities are manually executed and include:

- Spikes removal (triangles generated by meshing algorithms concerning points which actually are not connected each other);
- edges correction;
- correction of the normal orientation needed to orient consistently surfaces;
- triangles insertion to full gaps of the mesh due to a possible lack of data for that specific area of the object;
- polygons editing to reduce as much as possible the number of polygons to make the object lighter (optimization, filtering and decimation)

The mesh operation can be integrated also manually (by 3using 3D modeling software tool such as Presagis Creator) using the same cloud as reference.

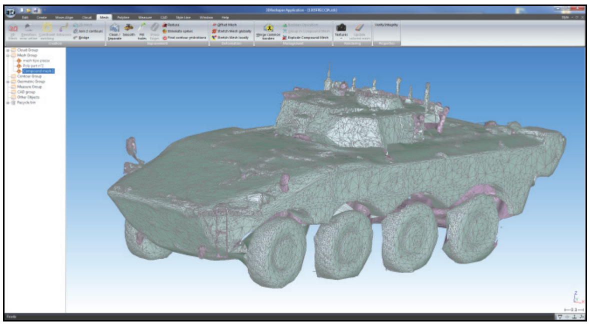

Figure 10: IFV 3D Model after the meshing operation executed on the points cloud

6.2. TEXTURING THE 3D DYNAMIC MODEL

For a realistic visualization of the model we move to map the 3D model by using the pictures taken by the SLR (single lens reflex), camera. Images are mapped on the surface already elaborated (mesh): the color of each pixel of the surface will be modified according the derived color from the texture (color mapping). Fotos are taken by view finder fish-eye and view finder with focus 50mm.

7. 3D DYNAMIC MODEL 3D MODEL ANIMATION

The IFV 3D model at this stage is done and well defined statically, visible by using both 3D CAD tools and graphic engines. In order to use the model for dynamic purposes in a simulated scenario it must be equipped by movement ability to make it realistic. To do this the tool Creator is used to split the model in several parts and assign to each of them a related degrees of freedom and constraints.

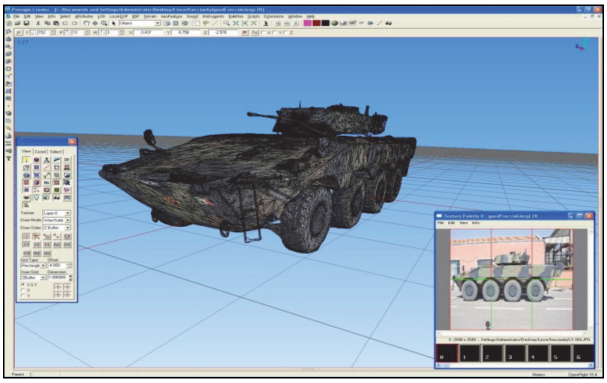

Figure 11 IFV 3D model after texturing operations executed in Presagis Creator Software

These are preliminary actions to get the model ready to implement (by writing programming code) the physics of the vehicle (i.e. engines, steering, shock absorbers, weapon systems, etc.).

The IFV 3D model has been divided into the following components:

- Outer hull: static part able to move in translation parallel to the terrain;
- wheels: rotating parts in a clockwise direction on a surface orthogonal to the terrain;
- tower: rotating part in inverse clockwise direction at round angle parallel to the terrain.

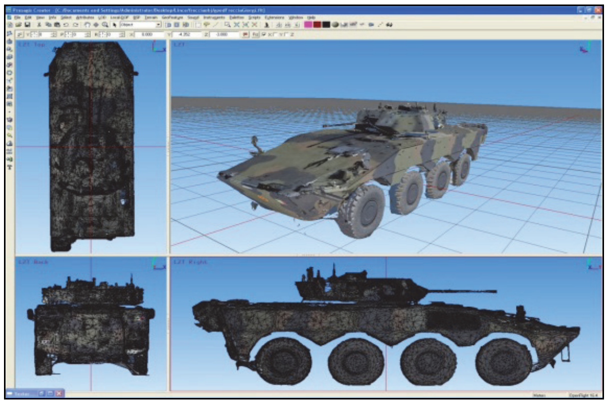

Figure 12: preliminary operations for getting the IFV 3D model ready for physics implementation

The process to replicate the IFV 3D model is complete. It is capable to interact with the simulated scenario. Using the tool Scenario Generator Animator (SGA) available at the NATO M&S COE, the Model is now associable with an entity in simulated scenarios. Its kinematic behavior is linked to the above entity and its related parameters (i.e. position, angle, position of the tower, speed and direction of movement, etc). In addition to the kinematic behavior we are able to associate radio sensors behavior, optical sensor behavior, fire capability.

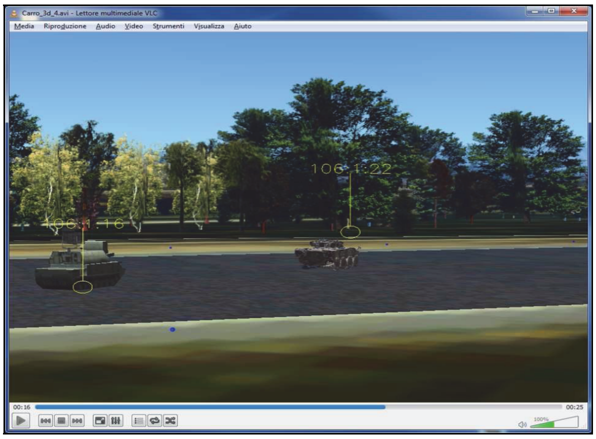

Figure 13: IFV 3D model in a virtual simulation

8. CONCLUSIONS

This article describes the main steps to be taken to recreate a 3D model of a real object by using the 3D Terrestrial Laser Scanner, a camera reflex with regular view finder, fish eye and appropriate software. The choice of the IFV is because this vehicle has been selected by the Italian Army as part of a project to integrate all Command & Control Systems. Making available a 3D model has been useful to import it in:

- electromagnetic environment simulator which takes in account the specific devises installed on board (radios, transmitting systems, jammer etc), frequencies uses, etc;
- Immersive 3D environments used for serious games and Virtual Simulations

Further researches are still on-going recreating other 3D objects with the aims of build a library of 3D object models that can be used at NATO M&S COE; additionally other research efforts are now devoted to define in details the physics of the IFV (this is useful not only for providing the IFV with a realistic behavior but also for developing a model that can be successively used for training purposes)

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HUMAN FACTORS' SIMULATION MODELS MILITARY RELEVANCE

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ABSTRACT

Over the last two decades, military forces have been deployed to areas where the history, culture, language, religious and tribal or family dynamics have played a key role in shaping military operations. In 2010, the revision of NATO strategic concept triggered a new cycle of the NATO Defence Planning Process, which identified the need for an efficient co-ordination of the Human Environment activities as one of the most critical capability shortfall for every mission type.

This year, the University of Genoa (ITA) started, in conjunction with an industrial consortium and with the support of NATO M&S Centre of Excellence, a research programme aimed at developing for the Italian Defence new simulation models, that take into account human factors (i.e.: culture, jeopardy, fear, aggression, etc.) in order to support the military decision makers in Theater of Operations. This new tool should significantly contribute to fill in the NATO capability gap.

Keywords: human factor, NATO operations, joint communication, cross-cultural awareness

1. INTRODUCTION

The focus of this paper is the relevance of human factors in modern military operations. Subsequent sections describe the impact of human factors on the accomplishment of the overall mission in a military operation, the need to develop a capability to efficiently manage the Human Environment activities and a Modelling & Simulation research programme that can support this capability development.

The present paper compares the capability need identified by the military side with the technological support that Modelling & Simulation can provide, highlighting the existing supply/demand relationship in the Modelling & Simulation marketplace. Since this paper is produced with the contribution of the NATO Modelling & Simulation Centre of Excellence in Rome (ITA), the area of investigation is very wide and rises up to the NATO alliance perspective, taking into account also specific studies conducted by single Nations.

2. HUMAN FACTORS IN MILITARY OPERATIONS

After the fall of Berlin Wall, the use of the military shifted away from the conventional confrontation of the Cold War model towards the numerous humanitarian and peacekeeping interventions of the 1990s. In 1992, the Petersberg Declaration of the Council of Ministers of the Western European Union incorporated within the European Security and Defence Policy a list of military tasks having a humanitarian nature, formulated as:

- "humanitarian and rescue tasks;
- peacekeeping tasks;
- tasks of combat forces in crisis management, including peacemaking." (WEU 1992)

In 2001, "the events of a single day, September 11, altered the trajectory of the US and the way it used its military over the next decade. A national strategy that had focused on countering regional aggressors and sophisticated attacks using weapons of mass destruction (WMD) was now confronted by an enemy that attacked the homeland with low technology in asymmetric and unexpected ways—individuals armed with box-cutters using hijacked civilian aircraft.

In the decade following 9/11, it became evident that the Cold War model that had guided foreign policy for the previous 50 years no longer fit the emerging global environment.

Key changes included:

- A shift from US hegemony toward national pluralism
- The erosion of sovereignty and the impact of weak states
- The empowerment of small groups or individuals
- An increasing need to fight and win in the information domain

In the midst of these changes, the US employed its military in a wide range of operations to address perceived threats from both nation-state and terrorist groups; to strengthen partner nation militaries; to conduct humanitarian assistance operations; and to provide defense support of civil authorities in catastrophic incidents such as Hurricane Katrina." (JCOA 2012)

It is therefore evident that, over the last two decades, both America and Europe changed their priorities and policies in the use of military, taking more in consideration the human aspects of military operations. The change of the geopolitical situation and the rise of new asymmetric threats triggered new military strategies that now have to understand the psychological, social and cultural reasons of a threat and vice versa the emotional impact of a military operation on civilians' perceptions.

This change on military strategies forced NATO to review its Strategic Concept in 2010. The new NATO Strategic Concept emphasizes the need to fight not only conventional threats, but also new ones like "extremism, terrorism, and trans-national illegal activities" and to foster security through the conflict prevention and crisis management. "The lessons learned from NATO operations, in particular in Afghanistan and the Western Balkans, make it clear that a comprehensive political, civilian and military approach is necessary for effective crisis management" (NATO Strategic Concept 2010). These statements triggered a new cycle of the NATO Defence Planning Process (NDPP) and posed the basis for new concepts like Comprehensive Approach, Cross-Cultural Awareness and Understand to Prevent.

Figure 1: NATO Defence Planning Process

3. CAPABILITY DEMAND

The NDPP is the five-step process – generally sequential and cyclical in nature – that NATO adopted since June 2008 in order to improve the necessary capabilities to initiate, sustain and successfully conclude its operations. Moving from the Strategic Concept, the NDPP establishes a single top level political guidance that provides objectives to be met by the Alliance planning. From the comparison between the capabilities needed to meet those objectives and the capabilities already existing, the process identifies the gaps that need to be filled in.

One of the most critical capability shortfall identified by the last cycle of the process is indeed the need for an efficient co-ordination of the Human Environment activities. To do that, first of all it is important to understand the human environment, and then to be able to efficiently engage it. "The operational environment encompasses not only the threat but also the physical, informational, social, cultural, religious, and economic elements of the environment. Each of these elements was important to understanding the root causes of conflicts, developing an appropriate approach, and anticipating second-order effects." (JCOA 2012)

Examples of failure in understanding the human environment are: ignore early signs of an insurgency, ignore tribal and cultural historical preferences, "causing the population to lose trust in the coalition" "and allowing terrorist and criminal elements to thrive." (JCOA 2012). These failures, therefore, can affect the "effectiveness in countering asymmetric and irregular threats from insurgencies and mitigating terrorist and criminal influences." (JCOA 2012). This enforces the importance of the concept of Understand to Prevent in order to face the new threats identified by the NATO Strategic Concept. "Threats in this new environment become diffuse, abstract and uncertain. Their identification, isolation and suppression are increasingly complicated since adversaries blend into the population, which hampers countering the threat and preventing collateral damage or unsought effects. Therefore, in current operational environments the population (the human factor) becomes a key element to take into consideration as far as military planning and conduct of operations are concerned." (MNE 6)

"It is paramount to know and understand the local culture," "so as to comprehend the dynamics and causes of local behaviors, attitudes and emotions, to be ultimately able to predict further reactions. Moreover, in these contexts it is also crucial to be cognizant of how the Coalition Forces' culture is perceived by the local population/actors in Theatre." "Consequently, culture is to be analyzed and incorporated in the different elements and features in which it can be broken down", "such as the physical – geography, social dynamics, economy and political situation but putting special emphasis on those sensitive and touchy factors more operationally relevant depending on the scenario. Gender, honor and revenge are among them." (MNE 6)

So, understanding the human environment goes through the awareness of cultural differences. A multinational experiment, conducted by a group of NATO Nations led by Spain (Multinational Experiment 6), developed the Concept of Cross-Cultural Awareness (CCA), analyzing the culture from an anthropological point of view, studying the psychosocial and psychological factors of culture and showing the results of a research that "focused on the perceptions of the most conflicting cultural factors affecting the relations between the militaries and local populations" (MNE 6 2010). This resulted in a number of recommendations, methodologies and conclusions for the implementation of CCA with regards to military operations.

Figure 2: Perception of militaries in the local population

CCA seeks to apply the Comprehensive Approach to current operations. "According to this approach, military forces become a contributor (probably the most important one at some stages but in a supporting role at some others) in the resolution of a conflict along with national and multinational government agencies, international and intergovernmental organizations, non-governmental organizations and the private sector. Furthermore, particularly against irregular adversaries and non-compliant actors, local (host nation) authorities, traditional leaders, military and security forces are to be acknowledged as an essential component for success." (MNE 6 2010)

Understanding the human environment is a key element for an effective planning and conduct of military operations. An efficient co-ordination of the human environment activities and their effective engagement are strongly affected by the perceptions of the most conflicting cultural factors in the local population. The second important aspect of the identified capability shortfall is, therefore, the engagement of the human environment through actions that influence positively those perceptions. An important example is the strategic communication, the so called "battle for the narrative in achieving objectives at all levels" "by influencing perceptions on a local or global scale" (JCOA 2012). The correct use of strategic communication or the decision to take actions that might influence positively perceptions in the local population are key for the accomplishment of the overall mission in a military operation.

The next step of NDPP is to setup a course of actions aimed at developing the human factors' capability described above, according to the NATO requirements. The course of actions will be apportioned to Nations, either individually, multi-nationally or collectively, and targets assigned for capability development for the subsequent implementation.

A possible target might be set to develop a capability aimed at training or supporting decision makers in Theater of Operations through the Understanding of Human Factors to Prevent, the Cross-Cultural Awareness, the use of Comprehensive Approach. With this respect, there is a need for a tool able to train or support decision makers and shape operations in accordance to the capability demand depicted above. Modelling & Simulation can be a cost-effective provider of this tool, by the creation of a simulation model that takes into account also Human Factors in the simulation tool actually used for training, decision support and experimentation (Bruzzone et al. 2004; Bruzzone, Longo, Merkuryev, Piera 2007; Frydman et al. 2009).

4. MODELLING & SIMULATION SUPPLY

Agent Based and Human Behavior Models - State of Art

Modelling human behavior requires an extensively interdisciplinary approach with the involvement of psychologists, anthropologists, sociologists, economists, medics and, of course, engineers and M&S experts. Putting human beings at the center of simulated systems is really very challenging but very important since people are the key element in several situations to analyze industrial, safety, security, military issues and many others areas. For these reasons, in the last 15 years a huge bibliography of publications and research works have been produced and provided the basis for technologies to model human behavior, that can supply the capability demand depicted above.

The paper "Crowd Modelling and Simulation Technologies" written in 2010 (Chen et al.), provides an interesting assessment of the major existing technologies for crowd modeling and simulation. Authors propose a two-dimensional categorization mechanism to classify existing work depending on the size of crowds and the time-scale of the crowd phenomena of interest.

If we look at other researches in this areas and we apply the classification based on the number of modeled humans we can easily divide researches in three main areas:

1. modeling individual or small groups;
2. modeling crowd in a defined area (stadium, metro station…);
3. modeling populations over an area (village, town region).

Some interesting works we have found in the area of single humans or small groups are, for instance, "A study on modeling of human spatial behavior using multi-agent technique" written in 2011 (Authors Chen; Yee Ming; Wang Bo-Yuan) This research follows the design and implementation of an agent-based modeling environment written in Java program language on AnyLogic simulation platform to facilitate observing the human spatial behaviors of electric taxis and passengers. An interesting sample of application in the military field in 2010 focused on small groups and where a game engine was used for the simulator development is "Behavior representation and simulation for military operations on urbanized terrain" of Zhuoqian Shen and Suiping Zhou where authors present a work on the design of an artificial intelligence (Al) framework for the bots in military operations on urbanized terrain (MOUT) simulations.

Concerning the level of big groups or population, that is the level of aggregation related to the researches described in this paper, we cite first of all the work "Enhancing multi-agent based simulation with human-like decision making strategies" (Norling, E; Sonenberg, L; Ronnquist, R 2001) where authors explored the enhancement of models of agent behavior with more "human-like" decision making strategies. A work related to civilian modeling is "Application of parallel scenario description for RoboCupRescue civilian agent" (Shinoda, K; Noda, I; Ohta, M; Kunifuji, S 2003) where authors propose an agent framework to describe behaviors of the general public in rescue simulations and implement an application for "Risk-Communication for disaster rescue".

We can also mention some works related to building design such as "Designing Buildings for Real Occupants: An Agent-Based Approach" (2011) (Authors Andrews Clinton J.; Yi Daniel; Krogmann Uta; Senick Jennifer; Wener Richard E.) or a very old work from Ozel in 1992 titled "Simulation modeling of human-behavior in buildings". For what concern crowd models we can cite "Integrating Information Theory in Agent-Based Crowd Simulation Behavior Models" where authors (Turkay, Cagatay; Koc, Emre; Balcisoy, Selim): it is an interesting work because proposes a novel behavioral model which builds analytical maps to control agents' behavior adaptively with agent-crowd interaction formulations.

Focusing on military and homeland security areas and on specific non conventional operations it is even more critical to consider human behavioral modifiers and mutual interactions for Computer Generated Forces (CGF). This area offers many solutions that have been developed over the years initially to solve basic issues (grouping and assigning joint basic commands) and subsequently to demonstrate intelligent capabilities. For instance, WARSIM is designed to train US Army command and staff. This constructive training simulation system can also be used to train commanders and battalion staff at the theatre level in joint and combined scenarios. The SAF Janus environment are of Semi-Automated Forces that was created in the Livermore laboratory (USA) in 1979 to model the effects of atomic weapons. In the 1990s it was modified and adopted by the Army as a standard model to teach Tactics at the small-unit level (squad/platoon/company). The software was adapted by France (until 1992) to the national norms prescribed by the Army operational and simulation research center (CROSAT).

"Spectrum" was designed in 1995 by the National Simulation Center in US as a command and control training simulation system, to address a deficiency in command and control training in Military Operations Other Than War (MOOTW), Stability and Support Operations (SASO) or again in complex contingency operations (CCO). It was designed while other military simulations were modelling force-on-force combat operations. Some CGFs are rather old but remain omnipresent in current M&S arena and still in use (i.e. Close Combat Tactical Training CCTT Saf). Another existing solution is OneSAF, a Constructive/Virtual and CGF (Computer Generated Forces) Simulation System that uses a high resolution terrain representation as well as an environment and scenario representation for stability and reconstruction operations, urban operations, support operations, etc. Recently updated, it is used for Concept Development and Experimetation (CD&E) and in international development and cooperation programs. With this regard, research projects have been designed to analyze how to create agents that can reproduce aspects to face such a kind of issues. For instance, Pythagoras (currently available at the SEED Naval Post Graduate School) is an agent-based environment originally developed in relation to the Albert Project, a USMC–international sponsored initiative that focused on human factors. In this context Pythagoras was designed to define and manage agents by assigning them behaviors based on motivators and detractors.

Researches lead by Raybourne in the area of emotional intelligence, transmedia and intercultural competence games (Raybourne 2009, 2011, 2012), must also be mentioned.

Moving to R&D projects developed by Prof. Bruzzone's research team, the first steps were made to apply behavioral models to process re-engineering in Industries: impact of human factors in companies strategies, ergonomic in complex conditions (company reorganization, off-shore platforms, crowd control, emergency management, etc.). In 2001, the research team presented a new research track for the development of new generation military CGF with "intelligent" autonomous behavior, especially focused on human factors. In 2003 PIOVRA (Polyfunctional Intelligent Operative Virtual Reality Agents), the first large project funded by the European Defence Agency in this area, was launched. From the very beginning, the idea was to create intelligent agents, interoperating in federations and able to direct units or to process tasks based on their specific perception and situation awareness; as a result, in 2007 PIOVRA interoperability within JMRM federation with JTLS by Rolands & Associates was demonstrated in several events in North America and Europe (Bruzzone et al.. 2006, 2007, 2008, 2011).

So far, several R&D activities on this subject have been developed and Prof. Bruzzone's Simulation Team currently applies IA_CGF (Intelligent Agents Computer Generated Forces) as elements and frameworks for introducing human behavioral models in simulation; IA_CGF was used for a demonstration in 2010 together with US JFCOM and presented during ITEC in London: in that event, after just three months from the real event, it was possible to create and simulate a complex scenario related to Haiti Earthquake where the Port au Prince population (over 2 millions) was modeled and analyzed in term of human factor evolution and behavior related to the crisis and the coalition food distribution operations. The presentation confirmed the effectiveness of bringing together many different simulators and tools, in that case JTLS, JCATS, IA_CGF, DI-GUY, VBS, Plexsys, etc, to support training (Bruzzone, Tremori, Massei 2011).

Now the research activities on this specific area are consolidated and focused on developing new IA_CGF modules as tiles to cover new areas over the wide spectrum of operations and scenarios that military forces are requested to face today (Bruzzone., Massei, Tremori, Bocca, Madeo, Tarone 2011).

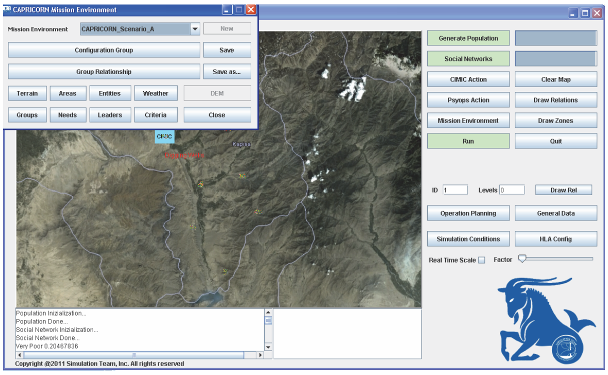

Figure 3: Capricorn and configuration of a CIMIC

CAPRICORN (CIMIC And Planning Research In Complex Operational Realistic Networks) is an EDA project devoted to develop new CGF representing not only military assets, but also regions, villages, parties and groups, moving forward to extend the use of these models from training purposes towards operational planning (Bruzzone, Tremori, Massei 2011). Another example of unclassified project is proposed by CGF-C4-IT, funded by the Italian MoD, where CGF are used in net-centric warfare to test the capabilities of different Command and Control (C2) architectures, maturity models and communication technologies in urban operations.

SIMCJOH Research Programme

The SIMCJOH (Simulation of Multi Coalition Joint Operations Involving Human Modelling) programme is a new research initiative of the University of Genoa (Italy). SIMCJOH Research Programme objectives are to study and develop new simulation models, in order to support the decision makers in Joint and Multi-Coalitions scenarios, considering a strong involvement of human factors with a particular focus on issues of refugees and civilians, natural disaster relief with presence of civilians in a theater of military operations; the initiative get benefits from innovative researches in population and human behavior modeling (Bruzzone, Bocca, Rocca 2006; Bruzzone & Massei 2007; Bruzzone, Tremori, Massei 2011; Bruzzone., Massei, Tremori, Bocca, Madeo, Tarone 2011; Mujica, and Piera 2012).

SIMCJOH Research Programme will lead to the creation of a simulator to be used in training, as a first step in experimentation phase, and later in operational planning in complex scenarios as described above.

The simulator will be realized federating via HLA (High Level Architecture) different models, according to technologies and standards state of art (Bruzzone et al. 1996; Kuhl et al. 1999; Massei et al. 2013). In SIMCJOH simulator federated models based on Intelligent CGF (Computer Generated Force) (such as IA_CGF), constructive simulators with different levels of aggregation (i.e. JTLS, JCATS etc.) and virtual simulators (i.e. VBS2, DI-GUY, ST_VP) will be integrated. For what concerns agents and the human behavioral models devoted to simulate population and civilians the effort of SIMCJOH research team will be focused on several critical issues, mainly summarized in the following elements:

- Models of human factors (i.e. stress, fatigue, food demand,…) to drive basic behavior of agents
- Models of social and parental networks for diffusion of information and perception of events by creating agents belonging to groups based on ethnic, political religious economics considering for instance mutual relationships between single agents and groups as proposed in Figure 4

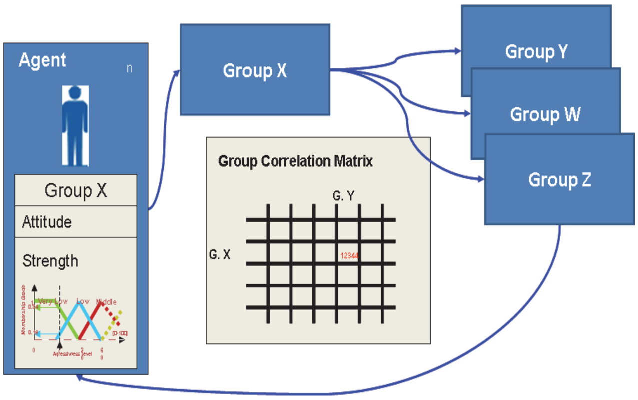

Figure 4: Sample of influence of correlation between groups based on Fuzzy Logic

The SIMCJOH federation will be executable and usable for different applications such as test & experimentation (or test & evaluation), training, operational planning. During the first phase of the Programme, the objectives to be achieved and the operational environment in which to run the new simulation models to be developed will be defined together with military users for field testing and validation (i.e. training). At this stage, the Concepts to be implemented (i.e.: Comprehensive Approach, Multicultural Awareness, Human Factor, Hybrid and non-conventional Threat, etc..) and the scenario (test case) in which the models will run (i.e.: Peacekeeping, Peace Enforcing, traditional conflicts, etc.) will be identified according to the state of art of the simulators and project constrains (budget and time). During the initial stages of SIMCJOH project authors are finalizing this aspect as well as the requirements for SIMCJOH federation and simulators to be integrated in. Based on the actual state of works preliminary conceptual models for defining proper Measures of Merits has been defined Such metrics are based on the impact of every single event considered in the scenario (i.e. number of casualties, number of rescued hostages…), on the impact of the 6 different PMESII effects (Political, Military, Economical, Infrastructural and Informative) and on the impact of the Countries analyzed and involved in the scenario and are summarized in the following formula.

$$\overline{MoM} = \sum_{i=1}^{n_e} I(t)_{e_i} f(t)_{PMESII_{e_i}} f(t)_{Country_{e_i}} H(t_{e_i} - t_o) H(t_f - t_{ei})$$

Where

n_e = number of events considered

$$I(t)_{e_i} = \begin{cases} 0 & \text{if } t \le t_{e_i} \\ \text{Impact of event } i \text{ over time} & \\ 0 & \text{if } t \ge t_{e_i} + \Delta t_{e_i} \end{cases}$$

And

$f(t)_{PMESII_{e_i}}$ impact of PMESII effects of event *i*

$f(t)_{Country_{e_i}}$ impact on different countries of event *i*

In a second time, military users will be identified for experimental phases.

Development phase for Federations and Models will be completed with the federation integration test and completion of statistical dynamic verification and validation phases based on execution of the federation. Finally, the simulation will be tested by military users during the accreditation phase to evaluate the effectiveness and efficiency and lead to the definition of requirements for an advanced system based on this study that could be deployed as an operational decision support system. Since the prototypal stage, SIMCJOH federation of simulators meets the expectation of an usable and useful tool, able to support the Defence Capability Demand and repay the investment. In fact, using this federation both the operational planners and the analysts will be able to conduct further experiments to evaluate different approaches to C2 in accordance with NATO Maturity Models (NATO NEC Maturity Models Command and Control - N2C2M2) (Bruzzone, Tremori et al. 2009). With this regard it should be noted that the Intelligent Agents Based Simulation will allow to add a new layer to complex scenarios, which takes into account the influence of human factors and the attitude for cooperation and coordination in multi-joint coalition operations. This will provide the opportunity to quickly test different alternatives based on quantitative data. Thanks to interoperability system based on SIMCJOH findings could reuse models and simulators developed for other operating environments and scenarios and will add functionality that will enable a considerable impact.

5. CONCLUSIONS

SIMCJOH Research Programme is a bottom-up initiative of a single Nation (Italy) that is trying to meet the military needs on capability development, identified through a top-down process. The expertise of University of Genova (ITA) together with the know-how of the Italian Industry and the excellence of NATO M&S CoE are proactively seeking for a tool that will support military operations in crisis management, where the human factor is the key for success. The relevance of this initiative resides in the inputs that can provide to the development of IA Based Simulation as well as the support to the transformational effort of NATO, contributing to fill the gap of the identified Capability Shortfall on Human Factors.

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