Proceedings of the 2012 Winter Simulation Conference
C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose, and A.M. Uhrmacher, eds

DEFENSE AND SECURITY APPLICATIONS OF MODELING AND SIMULATION - GRAND CHALLENGES AND CURRENT EFFORTS

Andreas Tolk

Old Dominion University
Engineering Management. & Systems Engineering
Norfolk, VA, USA

Nabil R. Adam

US Department of Homeland Security
Science & Technology Directorate, IDD
Washington, DC, USA

Erdal Cayirci

Electrical & Computer Engineering
University of Stavanger
Stavanger, Norway

Stefan Pickl

University of the Federal Armed Forces
Core Competence Center for OR
Munich, Germany

Randall Shumaker

Institute for Simulation and Training
3100 Technology Parkway
Orlando, FL, USA

Joseph A. Sullivan

Naval Postgraduate School
MOVES Institute
Monterey, CA, USA

William F. Waite

The AEgis Technologies Group
410 Jan Davis Drive
Huntsville, AL, USA

ABSTRACT

This paper presents the positions of seven international experts regarding current and future grand challenges for modeling and simulation (M&S) supporting the defense and security domain. Topics addressed include new interoperability issues, real-time analysis challenges, evolving military and training exercises, the future role and importance of Operations Research and M&S, modeling human teams and cultural behavior challenges, how to support successful co-evolving of research and academic programs, and the implications of enterprise postures and operational concepts of future M&S. In summary, all contributions focus on a particular facet that in summary help to understand the conceptual, technical, and organizational challenges we are currently facing.

1 INTRODUCTION

For several years, military applications have been the engine behind many developments in the M&S domain. Very likely every soldier of the armies in the North Atlantic Treaty Organization (NATO) has had some contact with M&S applications, whether during training and exercises or when participating in procurement projects or conduct operational analysis of various strategic, operational, or tactical options. NATO and the nations provided M&S supported training centers, such as the Joint Warfare Centre in Stavanger, Norway (Cayirci 2006). New supporting infrastructure ideas are discussed and new technologies are evaluated, such as captured by Cayirci et al. (2009). Textbooks are written capturing the knowledge for new engineers and scholars, such as Sabin (2012), Strickland (2011), Tolk (2012), and Washburn and Kress (2009). The topics of defense and security applications of M&S seems to be well covered and published. However, there are still important grand challenges open that require research.

The expert panel conducted during the Winter Simulation Conference 2012 brought experts from academia and industry together to highlight notable current efforts and to identify grand challenges for defense and security applications of M&S hoping to contribute to a research agenda supporting soldiers and decision makers.

2 NEW INTEROPERABILITY CHALLENGES (TOLK)

Without question, the application of M&S in the defense and security domain is a success story. Starting with individual simulators to train soldiers using their weapons and weapon systems effectively only some decades ago, we are looking a training support in which the borders between real systems with real people (live simulation), simulated systems with real people (virtual simulation), and simulated systems with simulated people (constructive simulation) no longer exist. The Live Virtual Constructive Architecture Roadmap (LVCAR) Final Report (Henninger et al. 2008) defines ways to integrate various approaches and paradigms into a common architecture supporting soldiers, in particular, for training. Both international simulation interoperability standards, the Distributed Interactive Simulation (DIS) protocol (IEEE 1278) as well as the High Level Architecture (IEEE 1516) were predominantly driven by the need of military applications to interoperate, and both of them are part of the Live-Virtual-Constructive Architecture Roadmap (LVCAR) efforts (Loper and Cutts 2008).

So why do we need to think about interoperability and new solutions? The reason is that the philosophical foundations for the current solutions are deeply rooted in the success stories of the past, and we do not like to look for alternatives when we have a working solution at hand. But what exactly are the success stories?

One can make the case that the board games like Go, Chaturanga, and Chess were used to teach the nobles and rulers the tenets of combat (Loper and Turnitsa 2012). Certain gaming blocks represent certain capabilities and values. These block are moved around on the board, representing the environment of the games. With a focus on training officers, these blocks later represented the typical components of warfare – infantry, cavalry, and artillery – and the board was replaced by maps. The philosophy was that blocks were moved around on the map until they were in reach of a well-defined action against the opponent, or they moved away from the opponent to avoid such actions. However, the philosophy was determined by moving blocks between cells on the board, following a set of rules. All these were shared between the players, and there was little room for interpretation.

Things changed technically, but not conceptually with the introduction of computers replacing the game blocks and boards. Initiated in 1983 by the Defense Advanced Research Projects Agency, the SIMulator NETworking (SIMNET) project was the first effort exploiting the new developments in computer communications and network technology for simulation. The project emphasized tactical team performance by bringing together armor, mechanized infantry, helicopters, artillery, communications, and logistics. All these simulation systems shared a common battle space. They moved around in this battle space, saw the other systems in this space, and were able to shoot at each other. The interactions were mainly driven by Newtonian physics. There was a common understanding underlying all models, cause and effect were well understood. IEEE 1278 standardized these ideas and is still successfully applied. Many simulation engineers prefer these standard to alternatives, as it is intuitively clear to them that a group of simulators (blocks) were moved around in the common battle space (board) and could interact with each other using well defined protocol data units (rules).

IEEE 1516 tried to introduce more flexibility by allowing users to define their objects to be changed within the federation, using the standardized Object Model Template to define Federation Object Models (FOMs). The Runtime Infrastructure also introduced a number of new services for better synchronization and efficient distribution of shared data. What is interesting, however, is that the commonly used federations are using FOMs that are mainly derived from the Real-time Platform Reference FOM (RPR-FOM), which was standardized to mimic IEEE 1278 in IEEE 1516 environments. In other words: we use another standard continuing to support the idea of one common virtual world in which distributed entities follow common rules. As stated in Tolk et al. (2011), the mental model behind all these developments remained the idea of one shared virtual battle space that was populated by individual independent aggregates and/or platforms that interact with each other. This paradigm works well for physical interactions in a world governed by Newtonian physics, but it falls short for socio-psychological models.

While traditional physical models that model the same effect can use scientific experiments as the common real world referent – and as in Newtonian physics effects are deterministic and well defined –, socio-psychological models are based on theories and models that may contradict each other. Davis summarizes his research in (Tolk et al. 2010, p. 914) as follows: *"However, the literature is fragmented along boundaries between academic disciplines, between basic and applied research, and between qualitative and quantitative research. ... Realistically, the research base is not mature enough to support a coherent expression of the body of knowledge. The uncertainties and disagreements are profound, on both subject-area facts and even the nature of evidence and the appropriateness of different methodologies. Those hoping to find a nicely compiled body of knowledge that can be used to write computer models will be disappointed. Further, they will often find that there are multiple competing "theories." And, even if a particular "theory" is chosen, it will be found upon inspection to involve numerous variants and uncertainties."* In other words, a new paradigm is needed that allows to express multiple facets to evaluate a problem. The idea introduced by Yilmaz et al. (2007) to use multimodels in parallel to look at alternative developments may provide a way. Like in weather forecasts, where multiple models are used in parallel to predict the future path of a hurricane, and all paths are then displayed on a common map to compare the various results, HSCB models may use the work described by Morse and Schloman (2011) to identify the common concepts that can be displayed as the agreed common map to display the results of such socio-psychological models. This grand challenge is not technical. The computational know-how is available. What needs to be changed is the underlying philosophical foundation, the way we think about using M&S to represent what we know about a problem. We need to move from traditional positivism, as represented by Newtonian physics, towards modernity and post-modernity approaches. Without embracing these new approaches, military M&S applications in support of HSCB modeling will not be successful.

3 REAL-TIME ANALYSIS CHALLENGES (ADAM)

Real-time analysis during incidents provides complex, adaptive systems analysis that support strategic and operational level planners at the department of homeland security and the defense communities. Consider, for example, an earthquake event in the New Madrid Seismic Zone with hundreds to thousands of people who are part of the field assessment, response, and recovery process, distributed across several counties and states. There is a need for these people to be able to collect information efficiently and intuitively, rapidly communicate it to national analytic centers, and to receive information that provides them with "investigative leads" about new hazards, infrastructure service disruptions, etc. predicted by complex modeling and analyses that have been rapidly returned to them while they are still in the field. This helps to control the consequences and focus resources after the earthquake.

Collection and management of real-time information from the field poses different challenges to different groups of stakeholders. Decision-makers must coordinate the "best possible response" to an emerging situation given current data and analysis results. Subject matter experts must filter a stream of noisy, incomplete data to pick out the consequential nuggets and identify relevant historical precedents.

Analysts need to identify effects of new real-time field information on an analysis begun already, projecting effects of new information, with updates from the field on simulation outcomes, and integrate real-time information to support simplification of models to allow dynamic reprioritization. Furthermore, analysts need to quantify the errors and uncertainty that can arise when combining real-time data streams with models based on historical data or analytic abstractions. Finally, field teams must both collect data and act on analysis results without adversely affecting other ongoing tasks. Real-time field information could be made available to the simulation system via multitude of devices (e.g., cell phones) and modalities such as text, audio, video, and images. This large diversity of real-time information needs to be processed in a unified manner.

As an illustrating example, consider the Complex Event Modeling, Simulation, and Analysis (CEMSA) system sponsored by the Science and Technology Directorate at the U.S. Department of Homeland Security (DHS) and developed by the Lockheed Martin Space Systems Company (Mehrotra 2012). CEMSA aims to develop and deploy a system which enables an analyst to rapidly integrate data, models and experts in order to arrive at credible consequences of multiple interacting complex disruptions to critical infrastructure and key resources. CEMSA is a net-centric and enterprise-wide system based on an open service oriented architecture and industry standards, such as provided by the Open Geospatial Consortium (OGC), e.g. their Keyhole Markup Language, Web Processing Service, Web Mapping Service, and Web Feature Service, and the World Wide Web Consortium (W3C), e.g. their Web Service Description Language. It reduces turnaround time, reduces costs, provides organic capabilities for risk analysis, enhances interoperability, and enables DHS to access and leverage the best available models within government, other agencies, partner universities, and industry.

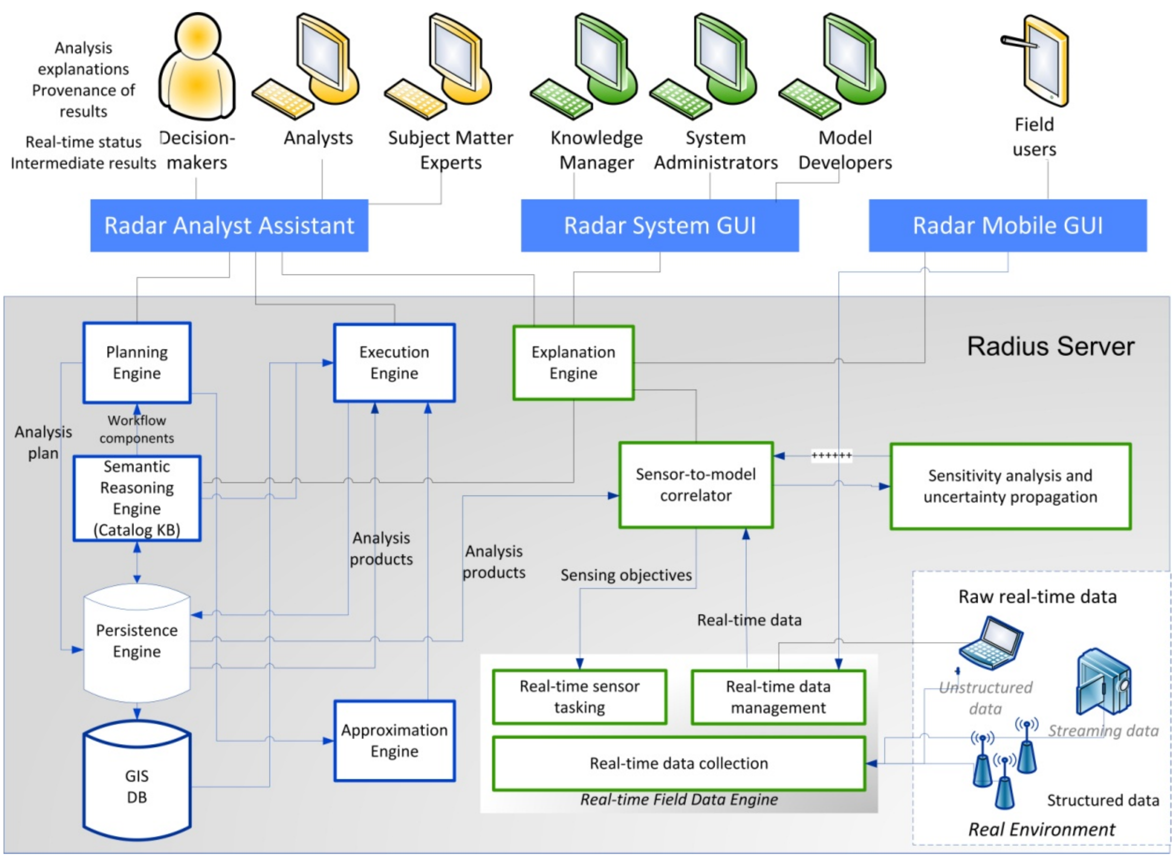

Figure 1: The Complex Event Modeling, Simulation, and Analysis (CEMSA)

As shown in Figure 1, CEMSA provides the following capabilities:

a. *Planning Engine*. Its functionalities include: i) making use of underlying business process as represented by the Functional Area Analysis (FAA) as well as the model ontology and DHS infrastructure Data Taxonomy; ii) selecting and composes appropriate models that satisfy such constraints as time, and fidelity; iii) invoking the approximation engine (see below) in the event the time constraint cannot be met; and iv) providing the analyst the capability to modify the model composition and replace selected models with others as he/she sees fit. CEMSA enables the user to modify the plan at any point in the process. This allows the user to have visibility and control of the system, and not have to deal with a static automated system.

b. *Approximation Engine.* It works in concert with the planning engine by applying statistical analysis to similar previous studies, captured in a knowledge base, to provide a rapid approximate answer.
c. *Semantic reasoning Engine.* It provides a knowledge base capturing previous studies, models, simulations and datasets. Each element is categorized using ontologies derived from DHS standards including the DHS Infrastructure Data Taxonomy (IDT).
d. *Explanation Engine*. It enables analysts to trace results to individual model and it associated inputs and outputs as well as provides error bounds for final results as a function of error bounds of each individual model.
e. *Model Ingestion Engine*. It allows CEMSA to maintain an open and flexible architecture that can be curtailed to the user's needs by having the ability to ingest models as needed. The primary requirement for adding models is that they contain an API so they can be wrapped as a service and ingested through the CEMSA service development kit (SDK).

Furthermore, CEMSA delivers real-time data capture and management, and quantifies the errors and uncertainty that can arise when combining real-time data streams with models based on historical data or analytic abstractions. CEMSA delivers five innovative capabilities that enable analysts and decision makers to understand and manage the results of CEMSA tools. The explanation interface supports real-time decision-making by tracing where new data caused a workflow to diverge from previous results. The execution monitoring interface presents the effects of new data on an analysis that has begun already. The multiple hypothesis representation and reasoning engine projects the effects of new data on workflow outcomes, and real-time data collection and management components populate that representation with updates from the field.

To address some of the challenges described above, the CEMSA's Real Time Data Collection module (RTDC) uses the following key insights to collect and process data from diverse sensors:

- Design of powerful higher level sensor and sensor resource abstractions that can hide sensor heterogeneities and diversity of platforms.
- Design of abstractions to simplify bindings between sensors and sensor data processing algorithms
- Design of mechanisms to mediate application needs with resource constraints of devices and networks
- Developing an implementation based on established standards and formats to the extent possible to support interoperability.

In the design of the RTDC module, CEMSA leverages both concepts and implementation code from the SATWARE semantic middleware for building sensor-based applications developed at UCI.

4 MILITARY TRAINING AND EXERCISES (CAYIRCI)

Although military training and exercises are the most advanced fields of application for military modeling and simulation and there are very powerful military live, virtual and constructive simulation systems, the M&S usage in the field is not yet mature enough. Agreements on terminology have not been reached, which creates confusion and frustration among both technical experts and operational staff. Moreover, procedures and methodologies which utilize M&S especially in military exercises are not optimal. Therefore, in this section, we clarify several terms and concepts often misperceived by the practitioners of the field.

4.1 Computer-assisted (CAX) Versus Synthetic Exercises

Computer assistance to an exercise is not limited to M&S. CAX support tools are used for two main purposes (Cayirci and Marincic. 2009), namely to *immerse the training audience into a realistic situation* so that they can train as they fight and to *assist the exercise planner(s) and exercise controller(s) in steering an exercise* towards the exercise and training objectives (ETO).

For the first purpose M&S tools and mediation-ware between the M&S tools and command and control (C2) systems are used. For the second purpose there are available exercise planning, exercise management, experiment design, and after action review (AAR) tools. An exercise that uses any set of these tools can be called as a CAX even if the set does not include M&S. Therefore, a CAX is not essentially a synthetic exercise (SYNEX). CAX does not have to be a command post exercise (CPX) either. A field training exercise (FTX) can also be conducted as a CAX.

4.2 Distributed Exercises Versus Distributed Simulation

Distributed exercises and distributed simulation are two separate concepts. It is not essential to support a distributed exercise with distributed simulation. In reality most distributed exercises are supported by centralized simulation systems. In a distributed exercise, the components of the exercise (i.e., parts of the training audience and exercise control structure) are deployed in remote locations. In a distributed simulation, parts of the simulation are run as separate processes. Therefore, a distributed exercise can be supported by a centralized simulation or a centralized exercise can be supported by a distributed simulation.

4.3 High Resolution Versus Tactical and Highly Aggregated Versus Operational Constructive Simulation Systems

High resolution simulations are entity level simulations where singular military objects, e.g. soldiers, tanks, aircrafts, are the primary objects represented in the simulation. The resolution of terrain data is high sometimes as specific as the plans of individual buildings. However, the simulated terrain is often limited (i.e., between 200 km × 200 km and 2000 km × 2000 km). High resolution simulations are better suited for the tactical level. However, they are not only for tactical level simulation. They provide higher resolution that may be required also for operational and higher level purposes. Therefore, high resolution simulation systems should not be called tactical simulations. Highly aggregated simulations are aggregate level simulations where collections of military assets, i.e., units, are the primary objects represented. They use lower resolution terrain data but they can simulate areas as large as continents. Similar to high resolution simulations, there is a tendency to call highly aggregated simulations operational level simulations, which is not correct. Aggregate level simulations may be very useful also for tactical purposes.

4.4 Multi-level Exercise Versus Multi-Resolution Simulation

Similar to the difference between distributed exercises and distributed simulation, there is a difference between multi-level exercises and multi-resolution exercises (Cayirci,2009). In a multi-level exercises, the training audience represents multiple levels of command hierarchy. This does not mean that simulation systems with multiple resolutions are required. On the other hand, to support a CAX with a single level training audience, multiple resolution simulations may be required. For example, to support a joint personnel recovery incident a high resolution simulation system may be required, although the training audience is at the joint force command level and a highly aggregated simulation system is used to support the overall exercise.

4.5 Live Exercise Versus Live Simulation

Live simulation refers to a simulation that involves real people operating real systems. For example, two pilots can be trained by using real aircraft in the air. In this case the aircraft and the pilots are real but the interactions between the aircraft are simulated and the simulation decides how effective the pilots and the aircraft act against each other. Similarly, all the weapon systems can be equipped with emitters, and all the equipment and personnel can be equipped with sensors. If the weapons are aimed and fired correctly, the emission by the emitters can be sensed by the sensors, which indicate a hit and/or a kill based on some stochastic processes. The definition of live simulations cause a debate about the scope of live simulations. In live simulations the interactions between the real systems and people are simulated, as explained above. Many experts believe that when a command and control center joins an exercise by using real C2 devices connected to a synthetic environment, it is also called a live simulation because C2 devices and the people using them are real. Although some experts do not agree, we concur with this interpretation. Live simulations are also often mixed with live exercises. In essence a live exercise is a live simulation although it is not a computer simulation. However, the usage of live simulations are not limited to live exercises. In reality a live exercise can also be supported by a constructive simulation system, and a command post exercise can be supported by a live simulation. For example, while one of the platoons is in the field running a live exercise, the other platoons of the company can be simulated in a constructive simulation system. Similarly, live simulation systems, like real command centers, can be used in a CAX.

4.6 Main Event/Incident List (MEL/MIL) Versus Simulation-Driven CAX

Contrary to the common belief, when there is a MEL/MIL, there is still a need for simulation, and there should not be a tradeoff between a MEL/MIL and a simulation. A good MEL/MIL is always needed to ensure that the exercise flows towards the ETO. However, the content of the MEL/MIL, the dynamic management of MEL/MIL and the synchronization of MEL/MIL with the simulation are very important:

- MEL/MIL should not script the decisions of the training audience (TA) or hinder the decision and planning processes of the TA.
- MEL/MIL should not script the results of the decisions taken by the TA.
- MEL/MIL should not be fixed and need to be dynamically maintained based on the performance of the TA and the ETO throughout the execution stage of an exercise.
- Situations can be created in simulations by only controlling situational forces. This suffices to synchronize simulation with MEL/MIL. However, the movement of situational forces should also be realistic.

5 FUTURE ROLE AND IMPORTANCE OF OPERATIONS RESEARCH (OR) AND MODELING AND SIMULATION (PICKL)

In a world, where interconnectedness, delimitation, complexity, dynamics and uncertainty play an ever increasing role, decision making has become ever more challenging and requires a *reflected analysis of the situation*. OR/M&S is sometimes defined as the “Science of Making Better” and delivers analysis through *qualitative and quantitative* methods to support decision makers.

5.1 Integration of Soft OR and Hard OR into an Holistic Approach

The methods’ bandwidth of Operations Research has changed over the last 70 years. Initially it used only quantitative methods and was strongly mathematical. Over the years the understanding of complexity grew and it became obvious that complex decision problems can rarely be solved with mathematical equations. Hence OR changed to address reality. Nowadays in addition to traditional hard OR, there are soft OR methods which capture and describe decision problems qualitatively, i.e. Influence Graphs, SODA (Strategic Options Development and Analysis), Scenario Building/Planning, AHP (Analytical Hierarchy Process), Delphi, SWOT (Strengths, Weaknesses/Limitations, Opportunities, and Threats) analysis.

5.2 CIMIC and Humanitarian Logistics

The application areas and opportunities extend over all business areas and most sciences, i.e. economics makes heavy use of OR methods like optimization. Logistics without OR support to improve efficiency seems to be bound to failure. Military decision makers increasingly use newer OR and simulation techniques methods as well. Last but not least, the new field of Humanitarian Logistics and CIMIC is based on soft and hard OR methods. Modeling and Simulation as part of OR together with modern information technology and high computational resources enables decision support in the very early phases by discovering problem areas that even analysts cannot always envision. The method Data Farming, for example, searches problem areas and supports decision makers delivering insights instead of numbers (Kleijnen et al. 2005). Often it is vital for decision makers to understand the different dimensions of a problem to make sound and robust decisions. Fuzzy data mining techniques belong to data farming as well as experimental design and modern soft computing approaches (like evolutionary algorithms).

5.3 Strategic Planning and IT-based Decision Support

Strategic planning requires a reflected understanding of setting the right goals and being aware of changing circumstances. OR supports defining goals and setting up controlling systems over-watching decisive parameters. Unexpected future events and developments can impair the implementation of previously formulated goals and plans or even make it impossible. If possible new developments should be considered beforehand and existing plans can be reviewed and modified when necessary. Hence, OR/M&S offers a whole methodological toolbox for decision makers from the level of strategic planning to operational business decisions. “Operations Research” is more than mathematical programming or statistical analysis; isolated “Modeling and Simulation” approaches with a single focus of training and visualisation have their limitations.

5.4 IRIS Integrated Reachback Information System – OR Cells and Adaptive CD&E

A holistic decision support procedure supports the flexible coordination between multiple disciplines and responsibilities (for example within the creation of OR cells and CD&E processes). Therefore OR/M&S is central in the area of IT-supported process optimization as well as issues regarding decision and game theory/strategic planning, particularly with a view to the background of international military experiments and service-orientated “reachback” conceptions. The so-called IRIS (Integrated Reachback Information System) approach focuses on the development of a technical platform that seeks to support the effective and efficient application and integration of soft and hard OR techniques within a distributed decision environment. Among others, Loechel et al. (2012) emphasize that holistic “Operations Research” approaches are the basis for an efficient and intelligent decision making process especially for military decision makers and operation analysts.

6 MODELING HUMAN TEAM AND CULTURAL BEHAVIOR (SHUMAKER)

There are many important training applications that make use of avatars driven by some form of artificial intelligence (AI) to represent human behavior. These include successful systems for learning negotiation skills (Hill et al. 2006), dealing with patients in clinical situations (Hwang et al. 2009), and classroom management for student teachers (Lopez et al. 2012). In virtually every case, due to the state of the art in behavior modeling, these behaviors are hand-crafted and embodied in code, making their development expensive and relatively inflexible. In the case of the teacher training system cited, the limitations of AI have been offset by using methods for relatively seamlessly introducing human control of the avatars (Mapes et al. 2011). While this creates a much more effective system than one that is fully automated, it requires relatively expensive dedicated manpower to overcome the technological problems of limitations in human behavioral modeling. Adapting current systems to a different culture, application, or situation is largely a manual process. It will remain so until better, and self-adaptive methods are created based on encoded models of cultural and behavior rather than encoded examples of behaviors. Creating the necessary model structures will require long term collaboration among psychologists, anthropologists, cognitive scientists and computer scientists. Populating the models will require considerable additional effort. There has been some good progress, and several funding agencies sponsor research in human social, culture and behavior modeling. Pending long term success in this and other efforts, are there any nearer term possibilities for improving avatars and agents in emulating realistic human behavior in relatively complex situations? Lessons learned from current systems indicate that effectiveness and believability are good for early exposure even with relatively simple cultural rules and situations, but degrades significantly on further exposure because of limited repertoire of behaviors. This indicates that there is potential for useful improvement with relatively modest improvements for specifying and implementing cultural information, pending availability of more comprehensive modeling capability.

For practical and theoretical reasons most avatars used for training applications are not, and should not be photo realistic – the image should reflect the relative cognitive capability. The primary objective is to accurately portray culturally significant social signals, and to recognize, to some degree, those generated by the people being trained. Verbal interactions are more difficult to simplify effectively than appearance, however given a focused discourse domain a reasonably effective short term dialog is already possible, and with better non-verbal cue recognition could remain effective in training for a longer period. Cognitive models that could offer near human level generation of discourse may never be available, however the appearance of natural language interactive systems such as IBM's Watson , and Apple's SIRI let us sidestep that problem for applications where large, well-vetted subject matter knowledge bases can be created and coupled with a context-sensitive dialog manager. Bidirectional non-verbal social communication added to this should produce what appears to be an adaptive subject-relevant interaction capability at near human levels, at least in focused areas of use. Research in a surprising non-training application, autonomous robotics, may have something to offer in providing these non-verbal aspects of communication. Advances being made in this domain in bidirectional social signaling and cultural-sensitive behavior generation should be directly applicable to human-avatar culturally-aware interaction.

A key objective of the Army Research Laboratory's Robotic Cooperative Technology Alliance (RCTA) is development of robot control software to enable robots to operate collaboratively with humans in a team. In addition the robot is expected to function within an ambient culture along with the team, understanding and recognizing social norms and behaving appropriately. The cognitive and behavioral models being developed are expected to allow robots to serve as a member of a human team, able to operate appropriately within a team context and within a populated non-team cultural environment. The development metaphor is that of a service animal able to effectively understand the social context, sense and understand human non-verbal and limited verbal signaling, and to generate functional equivalents. While these expected advances do not improve direct verbal interaction for existing systems, they may extend the time that suspension of disbelief is effective, and would certainly enhance the capability for producing scenarios with groups of avatars that are functioning within the learning environment but are not involved in direct discourse. Some recent papers on modeling robot team behavior (Schuster et al. 2011), non-team cultural behavior (Fiore et al. 2011), and multimodal bidirectional interaction (Lackey et al. 2011) are particularly relevant to avatar behavior generation for training.

7 CO-EVOLVING OF RESEARCH AND ACADEMIC PROGRAMS (SULLIVAN)

The following section is more a collection of ideas about topics that are not yet covered sufficiently in defense and security M&S research agendas. First, it's important to address the process of more systematically identifying grand challenges across expanding application domains, technology providers, policy-making bodies and education and research organizations. This observation applies nationally and internationally. The M&S community indeed has its own grand challenge that can be summarized as follows: *"How do we continue to co-evolve research and academic programs to anticipate needs of defense and security professionals?"*

In the recent past, the M&S community has remained successful by considering new application domains (e.g. healthcare), aggressively applying evolved technical capabilities (such as game-based training), considering the operating context (irregular warfare), integrating new disciplines (cultural anthropologists for HSCB) and by expanding and aligning core competencies to address all of the above. The challenge is to find out whether we can continue scaling this model as the application domains become more diverse and technology accelerates more rapidly? Is our Body of Knowledge developing at the right pace and into the right directions? Do we have the right level, scope and scale of education programs to educate the workforce? Are we making the most of new technologies, in particular social media and distributed learning technologies, to build and foster a community of life-long learners leading the modeling and simulation community? Are there opportunities to expand already robust coordinating bodies to improve collaboration across domains, the S&T communities and international communities?

It may be of value to have a look at the Modeling, Virtual Environments and Simulation (MOVES) Institute at the Naval Postgraduate School (NPS). Here, the following new application domains are currently explored: Healthcare, Cyber, Energy, Advanced Distributed Learning, and Homeland Security.

Following the schema introduced above, following changes in core science and technologies are considered and actively pursued doing research: Augmented reality, Mobile devices, Cloud and distributed computing technologies, Dependence on networks (cyber infrastructure), Sensor proliferation and sensor 'intelligence,' Web-delivered simulation technologies and social media, and Models of learning and expertise.

Of the application domains that present the more compelling grand challenges, it may be best for us to describe our efforts to help build a cadre of defense healthcare professionals with Master's-level background to help guide the application and development of M&S for the healthcare community. The necessary motivations, potentials and challenges, have been addressed in earlier publications, such as by Lowery (1994) as well as recently by Brailsford (2007). For the MOVES Institute, it has been a very interesting collaboration thus far. We are working with partners from the Uniformed Services University of the Health Sciences (USUHS). The healthcare community has many pressing examples of significant challenges that must be addressed across the domains of simulation. Some examples include:

1. To what degree can avatars be improved to augment or replace standardized patients and patient actor-intensive clinical skills training?
2. How can we make better use of mobile devices to provide updated and just-in-time training to improve responses of first-responders and individual Soldiers/Sailors/Airman/Marines?
3. How do we advance our ability to simulate humans to support training and for the development of new equipment and procedures?
4. What are the optimal training and rehearsal protocols for robotic-assisted surgical procedures?
5. What scenarios are most effective in improving and building team performance training?

The larger simulation community could benefit from the answers to these questions. Perhaps there are opportunities to leverage activities across NATO partnerships?

8 IMPLICATIONS OF ENTERPRISE POSTURES AND OPERATIONAL CONCEPTS OF FUTURE MODELING AND SIMULTION (WAITE)

In this section we address the fact and implications of business practice upon these areas and upon business practice itself. It is a homily that large, complex systems exhibit emergent behavior – that is, the (often) unexpected, holistic behavioral processes that are the consequence of the cardinality and relationships of a system's apparently simpler constituent entities and component processes. So too it is with the business process of M&S in today's word. Newer more powerful simulation technical capabilities; a more sophisticated and self-aware workforce; the presence of industrial institutions and collaboration of practitioners through those venues; and the burgeoning fruitfulness of M&S, in a wide variety of roles, over increasing diverse range of application domains themselves constitute a socio-economic system whose most apparent emergent property is that of enterprise scope M&S operations.

Our thesis is that *the very enterprise environments and ecosystems, which current M&S progressively inhabit, are the genesis of a whole class of 'grand' challenging issues – and opportunities – with which we must be prepared to deal forthrightly and energetically.* We will elucidate in sub-sections:

- What are the *circumstances* of this emergent property of the M&S community-of-practice;
- What are the *implications* of these circumstantial factors upon M&S technology, workforce, industry and business practice;

- What are the *challenges* in each area, and
- What *tactics and strategies* are prudent in order for the defense establishment to take advantage of this evolutionary progress.

8.1 Circumstances

Where previous generations of M&S practitioners performed their functions almost undetectably in technical 'backrooms' out of the purview of program managers and organizational officials, today's M&S professionals are accorded pride of place and professional identity alongside program managers, systems engineers, test and evaluation specialists, acquisition executives, and other diverse stakeholders in their respective enterprise environments. Prime facie evidence for this trend may be indicated by the list of particulars following, equally relevant within the defense establishment and beyond:

1. Simulation is becoming progressive ubiquitous with in programs, systems, administrative services, and operational functions.
2. Simulation collaboration within and beyond enterprise boundaries is becoming progressively evident, as M&S visions and roadmaps make apparent.
3. A self-conscious M&S workforce is emerging, supported by intentional, although still somewhat unsystematic recognition in official titles and support programs
4. Investment in M&S technology infrastructure, development, and use is beginning to be taken seriously.
5. The cost-effectiveness of M&S at the enterprise level is already documented by a copious anecdotal literature and further corroborative information is being systematically compiled to evaluate the return of investment (ROI).
6. There exists a considerable infrastructure for simulation industry professionals, such as societies, regional economic development groups, and national and international focus groups.
7. M&S's explicit relationships to other communities of practice and by associated stakeholders are becoming progressively explicit and appreciated.

8.2 Implications of Enterprise-Scope Business Practice

The defense community is coping so far as evidenced by vesting of authority for administration of OSD enterprise administration with the DOD M&S Committee, its executive agent the M&S Coordination Office, and the several peer organizations established for the military services. Despite these signs of progress toward addressing enterprise implication of M&S practice, however, we can hardly consider such efforts to be fully effective. M&S on the enterprise level cannot be administrated if M&S itself is highly fractured and governed by too many sub-groups with different interest. Examples are:

1. Modeling is properly appreciated to be a support function in support of its enterprise environment. This is not always supporting fundamental integrity of M&S disciplinary practice. It befits the appreciation of the emerging technical and professional disciplines systematic utility.
2. The scope of disciplinary reach within and among entire enterprise domains provides strong confirmation of the emerging ubiquity and therefore value of M&S practice.
3. The increasing sensitivity of defense enterprise mission-success to M&S is strong motivation to consider, with equal sensitivity to risk and opportunity, the enterprise-level of the significance of M&S.

8.3 Typical Challenges Pursuant to Enterprise-Based Simulation Practice

Pursuant the 'place' of M&S within defense enterprise-context motivates our continued address to the implications of this synoptic phenomenon. Accounts of a few instances of how simulation enterprise operations are creating distinctive challenges for the successful application of M&S for defense may serve to make concrete the associated risks, as well as to suggest what coping strategies are best advised.

1. From the perspective of M&S technology, a variety of considerations are apparent. Interoperability and the significance of standards is obvious and receives reasonable attention. Another area is conceptual modeling, which seems to be underappreciated as an effector of success in enterprise level practice.
2. The demand for a trained, self-conscious, and indivisible workforce increases commensurately. Current efforts to document the identification of the Body of Knowledge (BOK) are underway but progress is slow, although education and training of M&S professionals depend on it. Likewise, certification of M&S professionals is a matter of particular concern and deserve support for an enterprise level M&S success.
3. In the domain of business practice economics, effective investment management, predicated on systematic estimation and appreciation of ROI is essential. Furthermore, its associated risks and alternative opportunities must be appreciated in enterprise context. Today, however, there is no systematic business practice available for the systematic and intercomparable expression of the business case for either individual or collective M&S investment.

8.4 Recommended Tactics and Strategies for Simulation Enterprise Success

In an attempt to recommend some tentative solutions, there are a few injunctions that are considered necessary conditions for making substantive progress. They include the following:

1. *At the enterprise level*, take modeling and seriously. It is a seminal technology for the 21st century, it is here to stay, and to fail to address its implications challenges, issues and opportunities would be an abrogation of our responsibility to leverage the power of the technology *at the enterprise level* on behalf of the national defense mission.
2. *Strategic sensitivity matters*. Approach all M&S investment, management, and value recovery from a strategic perspective. The degree of intimacy of M&S in the emerging enterprise business practiced operating environment makes this an imperative not an option.
3. *Cooperate and graduate*. In a version of the business school adage cooperation across services, with other executive departments and agencies, and with industry at large, however challenging, is worth the effort. Sustained, systematic, stable and deliberate coordination needed in the face of continued dynamic emergence of enterprise simulation business practices.

9 SUMMARY

This compendium of ideas, challenges, and visions provides many facets through which the grand challenges for effective and efficient future support of the defense and security domain can be evaluated and analyzed. Although they are very different in nature, some common themes can be identified.

The focus for defense and security application is continuously moving away from traditional warfare towards the topics towards the challenges of human, social, cultural, and behavioral factors. New operational constraints require training and education, operational analysis, and potentially even procurement and acquisition to rely more on HSCB factors than on traditional force-on-force models to support them. Many of the challenges remain open.

Future technologies continue to provide support. Fostering innovation in the military M&S community and keeping pace with new technological developments, such as cloud computing and new computer developments, need to be continuously evaluated regarding their capability to close capability gaps or to increase current capability by making it more efficient or less expensive.

It is essential for M&S to clearly understand its role in the implications thereof. While many experts predominantly use M&S exclusively as a tool that is governed, administered, and determined by the rules and canons of research of the application domain, the self understanding of M&S as a discipline closely related to OR emerges. As long as the implications for M&S enterprise postures are not recognized by industry and the philosophical foundations are not laid by academia, we will not be able to make significant progress to the benefit of all M&S users.

Mathematic foundations are required not only for operational research, but also to better understand the epistemological roots of M&S. In particular for new operational domains that do not provide a single commonly accepted theory – like Newtonian physics for traditional models that focus on movement and attrition, while social science support multiple alternative theories at the same time – new approaches that are based on a solid mathematical framework are needed.

All these must be accompanied by flexible and supporting management. As well known from engineering management science, a working solution is based on appropriate tools that we have to develop, an educated workforce for which we must provide, and a supportive management that removes roadblocks and stovepipes.

The position statements compiled in this paper contribute to the perception of some of these challenges and provide some tentative solution proposals. The research agenda for M&S in support of defense and security application remains far from being closed. We have reason to be proud of the success stories of the past, but the number of grand challenges seem to grow with integrating new technologies and satisfying new operational requirements in a increasingly more complex environment.

REFERENCES

Brailsford, S. C. 2007. Advances and Challenges in Healthcare Simulation Modeling: Tutorial. In *Proceedings of the Winter Simulation Conference*, Dec 9-12, Washington, DC, 1436-1448.

Cayirci E., and D. Marincic. 2009. *Computer Assisted Exercises and Training: A Reference Guide*. John Wiley.

Cayirci, E. 2006. NATO's Joint Warfare Centre Perspective on CAX Support Tools and Requirements. In *Transforming Training and Experimentation through Modelling and Simulation - Meeting Proceedings RTO-MP-MSG-045*, Paper 1. Neuilly-sur-Seine, France: RTO.

Cayirci, E. 2009. Multi-Resolution Federations in Support of Operational and Higher Level Combined/Joint Computer Assisted Exercises. In *Proceedings of the Winter Simulation Conference*, edited by A. Dunkin, R. G. Ingalls, E. Yücesan, M. D. Rossetti, R. Hill, and B. Johansson, 1787 - 1797.

Cayirci, E., C. Rong, W. Huiskamp, and C. Verkoelen. 2009. Snow Leopard Cloud: A Multi-national Education Training and Experimentation Cloud and Its Security Challenges. In *Cloud Computing*, edited by M. Jaatun, G. Zhao, and C. Rong; LNCS 5931, pp. 57-68, Springer.

Fiore, S. M., N. L. Badler, L. Boloni, M. A. Goodrich, A. S. Wu, and J. Chen. 2011. Human-Robot Teams Collaborating Socially, Organizationally, and Culturally. Proceedings of the Human Factors and Ergonomics Society, 55(1):465-469.

Henninger A. E., D. Cutts, M. Loper, R. Lutz, R. Richbourg, R. Saunders, and S. Swenson. 2008. *Live Virtual Constructive Architecture Roadmap (LVCAR) Final Report.* Modeling and Simulation Coordination Office Project Report No. 06OC-TR-001, Arlington, VA.

Hill, R. W., J. Belanich, H. Lane, M. Core, M. Dixon, E. Formell, J. Kim, and J. Hart. 2006. Pedagogically Structured Game-based Training: Development of the Elect Bilat Simulation. *Proceedings of the 25th Army Science* Conference, edited by J. A. Parmentola and A. M. Rajendran, published by Tech Science Press 2008.

Hwang, Y., S. Lampotang, N. Gravenstein, I. Luria, and B. Lok. 2009. Integrating conversational virtual humans and mannequin patient simulators to present mixed reality clinical training experiences. *Proceedings of the International Symposium on Mixed and Augmented Reality.* 197-198.

Institute of Electrical and Electronics Engineers. *IEEE 1278 Standard for Distributed Interactive Simulation,* IEEE publication, Washington, DC.

Institute of Electrical and Electronics Engineers. *IEEE 1516 Standard for Modeling and Simulation High Level Architecture*, IEEE publication, Washington, DC.

Kleijnen, J. P. C., S. M. Sanchez, T. W. Lucas, and T. M. Cioppa. 2005. A User's Guide to the Brave New World of Designing Simulation Experiments. *INFORMS Journal on Computing* 17(3): 263-289.

Lackey, S., D. Barber, L. Reinerman, N. I. Badler, and I. Hudson. 2011. Defining Next-Generation Multi-Modal Communication in Human Robot Interaction. *Proceedings of the Human Factors and Ergonomics Society*, 55(1):461-464.

Loechel A. J., G. Mihelcic, and S. Pickl. 2012. An Open Source Approach for a Military Situational Awareness System. *Proceedings of the 45th Hawaii International Conference on Systems Sciences*. 1462-1471

Loper M. L. and D. Cutts. 2008. *Live Virtual Constructive Architecture Roadmap (LVCAR) Comparative Analysis of Standards Management.* Report M&S CO Project No. 06OC-TR-001, Alexandria, VA

Loper M. L., and C. D. Turnitsa. 2012. History of Combat Modeling and Distributed Simulation. In *Engineering Principles of Combat Modeling and Distributed Simulation,* edited by A. Tolk, 331-355, John Wiley.

Lopez, A. L., C. E. Hughes, D. P. Mapes and L. A. Dieker. 2012. Cross Cultural Training through Digital Puppetry. *International Conference on Cross-Cultural Decision Making*, San Francisco, July 21-25, 2012, in press.

Lowery, J. C., B. Hakes, L. Keller, W. R. Lilegdon, K. Mabrouk, and F. McGuire. 1994. Barriers to Implementing Simulation in Health Care. *Proc. Winter Simulation* Conference. Edited by M. S. Manivannan and J. D. Tew. Society for Computer Simulation International, San Diego, CA, USA, 868-875.

Mapes, D. P., P. Tonner, and C. E. Hughes. 2011. Geppetto: An Environment for the Efficient Control and Transmission of Digital Puppetry. LNCS 6774, Springer Heidelberg, 270-278.

Mehrotra, S., N. Venkatasubramanian, M.-O. Stehr, and C. Talcott. 2012. Pervasive Sensing, Event Detection and Situational Awareness. In *Securing Cyber-Physical Infrastructures: Foundations and Challenges*. Edited by S. Das, K. Kant, and N. Zhang, Morgan Kaufmann, 505-536

Morse, K. L., and J. Schloman. 2011. Toward Data Interoperability for HSCB Models. *Proceedings of the Spring Simulation Interoperability Workshop*, Curran Associates Inc., 149-158

Sabin, P. 2012. *Simulating War: Studying Conflict through Simulation Games.* Continuum.

Schuster, D., S. Ososky, F. Jentsch, E. Phillips, and A. W. Evans. 2011. A Research Approach to Shared Mental Models and Situation Assessment in Future Robot Teams. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 55(1):456-460.

Strickland, J. S. 2011. *Fundamentals of Combat Modeling.* Lulu.

Tolk, A. 2012. *Engineering Principles of Combat Modeling and Distributed Simulation.* John Wiley.

Tolk, A., P. K. Davis, W. Huiskamp, H. Schaub, G. L. Klein, and J. A. Wall. 2010. Challenges of Human, Social, Cultural, and Behavioral Modeling (HSCB): How to Approach them Systematically? *Proceedings of the Winter Simulation Conference*, edited by B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, and E. Yücesan, pp. 912-924.

Tolk, A., S. Y. Diallo, J. J. Padilla, and C. D. Turnitsa. 2011. How is M&S Interoperability Different from other Interoperability Domains? *Proceedings of the Spring Simulation Interoperability Workshop*, Curran Associates Inc., 12-20

Washburn, A., and M. Kress. 2009. *Combat Modeling.* International Series in Operations Research and Management Science, Springer.

Yilmaz, L., T. Ören, A. Lim, and S. Bowen. 2007. Requirements and Design Principles for Multisimulation with Multiresolution, Multistage Multimodels. *Proc. Winter Simulation Conference*, Dec 9-12, Washington, DC, 823-832.

AUTHOR BIOGRAPHIES

ANDREAS TOLK is Professor of Engineering Management and Systems Engineering with a joint appointment to Modeling, Simulation, and Visualization Engineering at Old Dominion University in Norfolk Virginia USA. He is also affiliated with the Virginia Modeling Analysis and Simulation Center. He holds a M.S. and Ph.D. in Computer Science from the University of the Federal Armed Forces in Munich, Germany. His email address is atolk@odu.edu.

NABIL R. ADAM is Professor of Computers and Information Systems at Rutgers University and a Fellow to the US Department of Homeland, Science & Technology Directorate Security - Infrastructure & Disaster Management Division. He is the Founding Director of the Rutgers University Center for Information Management, Integration and Connectivity (CIMIC), and the Director of the information Technology for Emergency Management Research Laboratory. He holds a Ph.D., M.Phil. and M.S. in Engineering, all from Columbia University, as well as a B.S. in Engineering from the Cairo University. His email is nabil.adam@hq.dhs.gov.

ERDAL CAYIRCI graduated from the Army Academy in 1986 and from the Royal Military Academy, Sandhurst in 1989. He received his M.S. degree from Middle East Technical University, and a Ph.D. from Bogazici University both in computer engineering in 1995 and 2000, respectively. He is currently the Head, CAX Support Branch in NATO's Joint Warfare Center in Stavanger, Norway, and also a professor in the Electrical and Computer Engineering Department of University of Stavanger. His e-mail address is erdal.cayirci@uis.no.

STEFAN PICKL is director of the Competence Center COMTESSA and chair for Operations Research at the University of the Federal Armed Forces . He is counselor to the Center for the Advanced Studies of Algorithms (CASA) at the University of Nevada and associated member of the Center for Network Innovation and Experimentation (CENETIX) of the Naval Postgraduate School Monterey, CA. Since 2010 he is chair of the advisory board of the German Society for Operations Research. His email address is stefan.pickl@unibw.de.

RANDALL SHUMAKER is Director of the Institute for Simulation and Training at the University of Central Florida in Orlando Florida USA and Professor of Industrial Engineering and Management Science with a joint appointment in Electrical Engineering and Computer Science. He holds a M.S.E. and Ph.D. in Computer Science from the University of Pennsylvania in Philadelphia Pennsylvania USA. His email address is shumaker@ist.ucf.edu.

JOE SULLIVAN is Director of the Modeling, Virtual Environments and Simulation (MOVES) Institute at the Naval Postgraduate School in Monterey California USA. He holds a B.S. in Computer Science from Catholic University of America and a M.Sc. in Computer Science from NPS. He attended the Aviation Officer Candidate School and was commissioned in October 1986. He has been a Military Instructor since 2001. His current rank in the US Navy is Commander. His email is sullivan@nps.edu.

WILLIAM WAITE is founder, chairman of the Board of Directors, BOD and Chief Technology Officer of the AEgis Technologies Group. He holds an M.S. in Physics from the Pennsylvania State University and an M.B.A. from the University of Alabama in Huntsville. His email address is bwaite@aegistg.com.