THE 5TH INTERNATIONAL DEFENSE AND HOMELAND SECURITY SIMULATION WORKSHOP

SEPTEMBER 21-23 2015

BERGEGGI, ITALY

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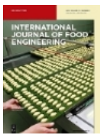

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It is a great pleasure and honor to welcome you on the International Defense and Homeland Security Simulation Workshop (DHSS 2015).

Building on the success of previous DHSS editions, the themes DHSS 2015 is focused on are that of concepts, methods, techniques and tools related to the use of Modeling & Simulation in Defense and Homeland Security applications. Even if this is a quite new workshop, previous editions have been successfully held in Rome (2011), Vienna (2012), Athens (2013) and Bordeaux (2014).

The high scientific quality of DHSS, is proved by the fact that its papers are indexed in one of the most important scientific data bases in the world, the so-called SCOPUS. In addition, DHSS papers are even more referenced thanks to their international visibility and the excellent quality contributions they provide.

The Workshop is the perfect forum to foster collaborations, networks and relationships for knowledge transfer. In addition DHSS provides the ideal framework to learn, share and problem-solve thanks to constructive discussions and debate amongst delegates from diverse cultural and contextual settings. The Organization Committee has made a great effort to set up interesting technical sessions and has done all in its power to unite scientists, world leaders and experts from research institutions, industry, agencies, policy makers, and governments to address current challenges and highlight novel solutions.

We hope you will join us in Bergeggi, a beautiful city by the sea in the Italian Riviera.

We look forward to welcoming you to an inspiring, educational and enjoyable program.

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DOMAIN MODELING IN SUPPORT OF ADAPTIVE INSTRUCTIONAL DECISIONS IN THE GENERALIZED INTELLIGENT FRAMEWORK FOR TUTORING

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ABSTRACT

This paper focuses on aspects of domain modeling for Intelligent Tutoring Systems (ITSs), adaptive training tools to support one-to-one computer-based instruction. Domain modeling represents knowledge for a particular task or concept and includes: domain content (a library of scenarios or problem sets); an expert or ideal student model with measures of success; and a library of tactics or actions (e.g., questions, assessments, prompts, and pumps) which can be taken by the tutor to engage or motivate the learner and optimize learning. Today, ITSs support well-defined domains in mathematics, physics, and software programming. Since the military often operates in complex, dynamic, and ill-defined domains, it is necessary to expand the scope of domain modeling. We examined domain knowledge representation across a variety of dimensions: task domains, complexity, definition, and physical interaction modes in order to understand instructional options and drive adaptive training decisions.

Keywords: adaptive training, domain modeling, intelligent tutoring systems

1. INTRODUCTION

ITSs have been applied in well-defined, cognitive domains which include mathematics, physics, chemistry, and software programming languages. The future holds more challenging domains for ITSs which include military instruction. We envision the use of ITSs to drive and adapt military instruction in existing military simulations (see Figure 1).

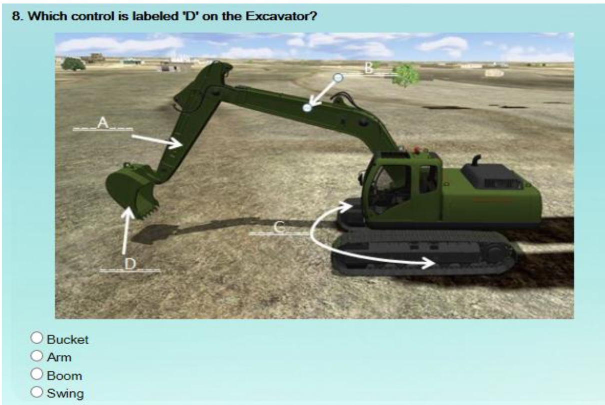

Figure 1: Military Construction Equipment Training

Military instruction is in many cases more challenging due to the large degrees of freedom encounter by learners during training. For example, learners in serious games have a large number of options with respect to actions available. This raises the complexity of these training and education environments compared to more process-oriented domains. Another level of complexity is encountered in modeling teams of learners as most military tasks also involve collaborative roles.

To dissect this problem of domain complexity in adaptive instruction, we should address how ITSs function and illustrate their decisions with respect to learners and training environments. ITSs are composed of four typical models: a learner or trainee model, an instructional or pedagogical model, a domain model, and a communication model (user interface). The domain model typically includes an expert or ideal student model by which the ITS measures, compares and contrasts the progress of the learner toward learning objectives. The domain model also includes the training environment, the training task and all of the associated instructional actions (e.g., feedback, questions, hints, pumps, and prompts) which could possibly be delivered by the adaptive system for that particular training domain. Adaptive training system agents observe changes in the learner's states (e.g., workload, engagement, performance and emotions) and respond through interactions with the learner (e.g., feedback, direction, support) or changes to the training environment (e.g., increase or decrease problem or scenario challenge level to match the learner's state or domain competency) as shown in Figure 2.

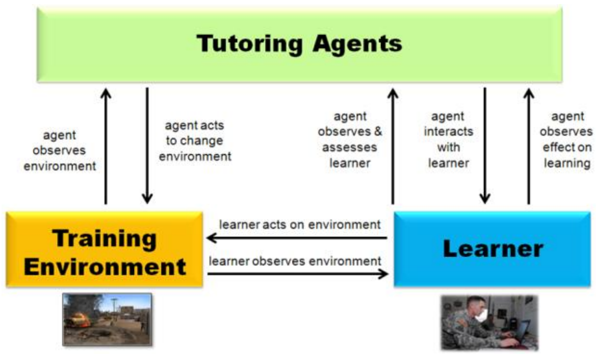

Figure 2: Adaptive Interaction between Learners, Training Environments and Tutoring Agents

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This interaction is an essential design element in the Generalized Intelligent Framework for Tutoring (GIFT; Sottilare, 2012; Sottilare, Brawner, Goldberg, and Holden, 2012; Sottilare, Holden, Goldberg, and Brawner, 2013), an open-source architecture (tools, methods, ontology) for: authoring ITSs; managing instruction during adaptive training experiences; and evaluating the effect on learning, performance, retention, and transfer.

2. DIMENSIONS OF DOMAIN MODELING

Domain knowledge may be represented across a variety of dimensions: task domains (cognitive, affective, psychomotor, social, and hybrid domains); task complexity (simple, compound or multifaceted tasks); task definition (well-defined, ill-defined or unknown measures of success), and physical interaction modes (static, limited dynamics, enhanced dynamics, and full dynamics also known). Our goal was to understand how to represent domains so GIFT could optimally select tactics (actions by the tutor) based on the optimal selection of strategies (plans for action grounded in instructional theory) and instructional context determined by the domain model as shown in the updated learning effect model (Figure 3).

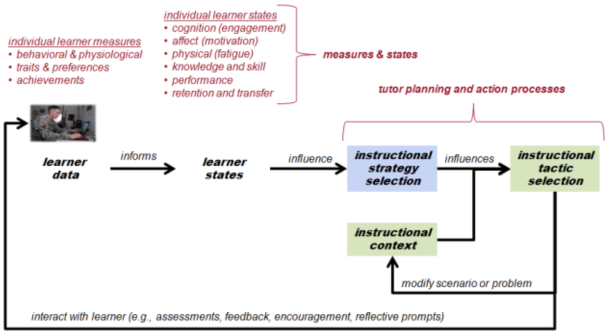

Figure 3: Individual Learning Effect Model (Sottilare, Sinatra, Boyce, and Graesser, 2015)

2.1. Task Domains for Adaptive Training Systems

First, we examine representations of task domains: cognitive (Bloom and Krathwohl, 1956), affective (Krathwohl, Bloom, and Masia, 1964), psychomotor (Simpson, 1972), and social (Soller, 2001). Understanding the dimensions of these domains can facilitate identification of critical learning and performance measures and reduce the burden of authoring adaptive training systems.

2.1.1. Modeling the Cognitive Domain

Sometimes called the *thinking* domain, tasks in this domain stress the learner's thinking capacity (workload management), problem-solving capability, decision-making, and focus or engagement. The determination of cognitive states uses learner behaviors to indicate increases in complex and abstract mental capabilities (Anderson and Krathwohl, 2001). Of significance in cognitive learning are attention, engagement, visual and spatial processing, and working memory.

A revision of Bloom's taxonomy (Anderson and Krathwohl, 2001) tracks a series of behaviors from low-cognitive state to high as follows: *remembering*- the learner's ability to recall information, *understanding*– the learner's ability to organize, compare, and interpret information, *applying*- the learner's ability to use information to solve problems, *analyzing*- the learner's ability to examine information and make inferences from that information, *evaluation*- the learner's ability to use information to make optimal judgments, and *creating*- learner's ability to build new models (e.g., plans) from information.

Most of the ITSs in existence today focus on this task domain. Examples include model-tracing (also called example tracing) tutors which use a set of steps to walk the learner through the process of solving a problem. Mathematics, physics, and software programming are the most common types of model-tracing tutors. These domains constitute simple procedural tasks.

Matthews (2014) notes organizations generally do a good job of training relatively simple skills. However, a more challenging goal is to teach higher order cognitive skills such as decision-making and judgment. The military has large investments in partial-task and scenario-based training systems which use relatively fixed processes to guide the learner based primarily on individual and team performance measures. A concern with these systems is that military personnel learn how to win within the constraints of the system but the effect on learning, retention, and transfer is not well understood. Research is needed to build adaptiveness into these training systems and thereby optimize deep learning. A goal of this research is to reduce the time to competency to allow time for over-training and deeper learning experiences which transfer more efficiently to the operational environment. As the often cited paper on transfer of training (Baldwin & Ford, 1988) discusses, transfer occurs through more than repeated practice, rather it is providing opportunities through differing views and representations of content, for the mental abstraction which provides the cognitive connection needed to move from training to operational contexts.

2.1.2. Modeling the Affective Domain

Sometimes called the *feeling* domain, tasks in this domain are intended to develop *emotional intelligence* or skills in self-awareness and growth in attitudes, emotion, and feelings where the goal is to manage emotions in positive ways to relieve stress, communicate effectively, empathize with others, overcome challenges, and defuse conflict (Goleman, 2006). While listed as separate domain, affect has an interdependent relationship with cognition. For example, cognitive readiness, the capability to maintain performance and mental well-being in complex, dynamic, unpredictable environments which may elicit affective responses. Dimensions of cognitive readiness, according to Kluge and Burkolter (2013), include concepts such as risk taking behavior, emotional stability and coping which may be considered part of the affective domain.

A revision of Bloom's taxonomy (Anderson and Krathwohl, 2001) tracks a series of behaviors from low-affective state to high as follows: *receiving*- the learner takes in information, *responding*- the learner takes in information and responds/reacts, *valuing*- the learner attaches value to information, *organizing*– the learner sorts information and builds mental models, *and characterizing*- the learner matches mental models to values and beliefs ultimately influencing (e.g., promoting or limiting) the learner's behavior.

Very little training (outside of classroom-based training) is currently provided to exercise/grow skills in this important task domain and almost no adaptive training has been created to support this domain. Research is needed to understand measures for this task domain, developing low-cost methods to determine the learner's affective state (Carroll, Kokini, Champney, Fuchs, Sottilare & Goldberg, 2011), and any unique characteristics required in authoring affective domain scenarios (Sottilare, 2009).

2.1.3. Modeling the Psychomotor Domain

Sometimes called the *doing* or *action* domain, tasks in this domain are associated with physical tasks (e.g., marksmanship) or manipulation of a tangible interface (e.g., remotely piloting a vehicle), which may include physical movement, coordination, and the use of the motor-skills. Development of motor-skills requires practice and is measured in terms of speed, precision, distance, procedures, or techniques during execution (Simpson, 1972). Simpson's hierarchy of psychomotor learning ranges from low to high: *perception*– the ability to use sensory cues to guide motor activity; *set or readiness to act*; *response*– early stages of learning a complex skill through imitation and trial and error; *mechanism*– habitual learned responses; *complex overt response*– skillful performance of complex movements; *adaptation*– well-developed skills that are modified to support special requirements; and *origination*– the development of new movement patterns to fit unique situations.

While this domain is well represented in military training, research is needed to build adaptiveness into these training systems and thereby optimize deep learning. A goal of this research is to reduce the time to competency to allow time for over-training and deeper learning experiences which transfer to the operational environment.

2.1.4. Modeling the Social Domain

Sometimes called the collaborative domain, tasks in this domain and include a set of collaborative characteristics or measures of learning in the social domain as defined by Soller (2001): *participation, social grounding*- team members "take turns questioning, clarifying and rewording their peers' comments to ensure their own understanding of the team's interpretation of the problem and the proposed solutions", *active learning conversation skills* - quality communication, *performance analysis and group processing* - groups discuss their progress, and decide what behaviors to continue or change (Johnson, Johnson, and Holubec, 1990) and promotive interaction - also known as win-win this characteristic occurs when members of a group perceive that they can only attain their goals if their team members also attain their goals.

However, it is not as simple as adding up the performance of each individual team member to find the performance of the team. Feedback which is appropriate for an individual team member may be inappropriate to be broadcast to the whole team. For this reason, we are developing models within GIFT at both the individual and team level as shown in Figure 4.

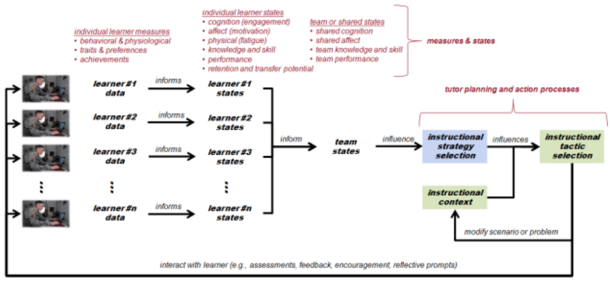

Figure 4: Team Learning Effect Model (Sottilare, Sinatra, Boyce, and Graesser, 2015)

2.2. Task Complexity and Adaptive Instruction

Next, we examine representations of task complexity for domain modeling. Task complexity refers to the level of challenge and the range of difficulty in understanding and performing the task. Task complexity can range from simple procedural tasks to more complex multifaceted tasks. Task complexity is important in accessing the near-term performance of the learner during adaptive training experiences. Referring back to the Individual Learning Effect Model in Figure 2, it is easy to see that the ITS's instructional options fall primarily into two categories of tactics or actions based on Vygotsky's Zone of Proximal Development (ZPD; 1978): interact with the learner to assess their performance, provide feedback or encouragement, or engage them in a reflective discourse; or modify the problem or scenario to more closely match the capabilities (knowledge and skill) of the learner.

Understanding task complexity along with learner capabilities is essential in supporting adaptive instructional decisions. Per the ZPD (Vygotsky, 1978), when the learner's level of domain competency does not match the complexity of the task, the learner is either bored when the task is too easy or anxious (stressed) when the task is too difficult. If the learner is bored, instructional options in adaptive training systems include increasing the complexity of the problem or scenario or reducing the amount of scaffolding or support provided by the ITS. If the learner is anxious, the instructional options are to reduce the complexity of the problem or scenario or increase the amount of scaffolding or support.

2.3. Task Definition and Adaptive Instruction

Variable task definition refers to how well the domains are understood in terms of measures of performance. Measures of performance are typically most effective when the problem space has clear boundaries / constraints and is well-defined. Well-defined domains (e.g., mathematics) typically have one correct path to a successful outcome and a set of specific measures of success. Ill-defined domains (e.g., leadership) may have multiple paths to successful outcomes, and tend to have less defined measures of success. The representation of task definition in adaptive training systems is essential to understanding measures of success.

Human Factors Engineering (HFE) has developed techniques to assist in further defining this domain. Work Domain Analysis (WDA) models a system in terms of the environmental, physical, or social constraints placed on a user (Naikar, 2013). In ITSs, this would be the composition of the goals of the system, the rules which underlie those goals, and how those constraints are represented to the learner. The second step to WDA is to break down the system in terms of requirements, which is specifically applicable to an ITS architecture (e.g., GIFT). Called an abstraction-decomposition matrix, each level of constraints is broken down according to subsystems to provide as understanding of performance at every level. From there, a Hierarchical Task Analysis (HTA; for a review see Stanton, 2006) can analyze the domain and break it down into a series of plans which are composed of tasks and subtasks to help understand and develop success criteria.

Today, ITSs which support well-defined task domains use specific measures to compare and contrast learner performance to an expert model or minimum standard. While it may not be possible to define specific measures for ill-defined domains, it may be possible to define constraints or policies which must be followed by the learner. The WDA combined with the HTA can help to clarify those relationships and provide key concepts that the learning instruction must include. A deviation from a successful path to an unsuccessful path results in initiation of action by the ITS.

2.4. Physical Interaction and Adaptive Instruction

Finally, we examine modes of dynamic interaction. Modeling the type and degree of physical interaction may impact transfer or the degree to which knowledge and skills developed in training are used in the operational environment. Although physical interaction via tangible user interfaces has received a lot of interest both in the commercial and classroom environment, empirical research on the impact of learning outcomes is sparse. The terms *intuitive*, *collaboration* and *engagement* are often mentioned, but the supporting data is missing. However studies performed at Stanford University have begun to show progress on the effects of learning (Schneider, Jermann, Zufferey, & Dillenbourg, 2011; Schneider, Wallace, Blikstein, & Pea, 2013).

Further supporting the role of tangible interfaces in learning, in a recent review on the impact of effect of manipulatives on learning, Pouw, van Gog, and Paas (2014), challenge two of the common perceptions of physical interaction and learning: 1. physical interactions, due to their richness, impose a higher cognitive load, and 2. transfer of learning involves a change from concrete representation to symbolic, negatively influencing learning. They respond to these views arguing for terms that they called embedded and embodied cognition. For embedded, they claim that in certain situations the added richness can alleviate cognitive load by embedding the learning cognitive activity into the environment. For embodied they argue that instead of changing the representation from concrete to symbolic, working with manipulatives involves the use of sensorimotor processes that draw on the perceptual and information rich nature of the interaction.

The representation of this embodied cognition depends on the type of physical interaction and how it engages both the perceptual and motor systems of the user. We have defined four levels of physical interaction in support of adaptive training: static, limited kinetic, enhanced kinetic, and full kinetic.

Static training environments (e.g., desktop computer training) allow the learner to perform primarily cognitive tasks (e.g., decision-making and problem solving). Limited kinetic tasks allow for full gestures, and limited motion in a restricted area. Movement and tracking of the learner from standing positions to kneeling, sitting or supine positions is supported so the range of physical tasks is broader than in static tasks.

Limited kinetic environments support hybrid (cognitive, affective, psychomotor) tasks where a larger degree of interaction with the training environment and other learners is critical to learning, retention, and transfer to the operational environment. Decision-making and problem-solving tasks may be taught easily in a limited kinetic mode along with tasks requiring physical orientation (e.g., land navigation).

Enhanced kinetic environments support tasks where freedom of movement and a high degree of interaction with other learners are critical to learning, retention, and transfer to the operational environment. Building clearing and other team-based tasks may be taught easily in an enhanced kinetic mode.

Full dynamic mode transfers tutoring to the operational environments and could also be called embedded training or in-the-wild training. Full dynamic mode is critical to support tasks where a very high degree freedom of movement and a high degree of interaction with other learners are critical to learning, retention, and transfer to the operational environment.

It is anticipated that psychomotor and social tasks may be best taught in full dynamic mode or an environment more closely resembling the operational environment. Research has shown that retrieval of learned information is better when the original learning context is reinstated during task performance and that contextual dependencies also extend to perceptual-motor behavior (Ruitenberg, De Kleine, Van der Lubbe, Verwey, and Abrahamse, 2012). This supports the notion that a misalignment between physical dynamics in training tasks will slow transfer of psychomotor skills during operations, and that a better alignment of the physical aspects of training tasks with how they will be performed on the job will result in more efficient transfer of motor skills.

3. IMPLICATIONS FOR PRACTICE

The progress that has been made in domain modeling, along with current research needs, does not exist in isolation with respect to ITS development. Understanding that the domain model is one of four core ITS models along with the pedagogical, learner, and communication models, respectively. It is important to recognize that advancing the state of the art within one model will have an influence on the others. For example, establishing measures for the cognitive domain will influence the data structure requirements of the learner model and, in turn, the physical sensors that might be required to populate the model. Likewise, developing adaptive training for psychomotor domains in *full dynamic mode* might require a paradigm shift in configuring the communications module for ubiquitous, natural user interfaces instead of computer interfaces.

The Generalized Intelligent Framework for Tutoring (GIFT; Sottilare, 2013; Sottilare, Sinatra, Boyce & Graesser, 2015) was designed with those aforementioned domain modeling challenges in mind. As the name suggests, GIFT was designed to be domain independent, and therefore generalizable to different domains including associated interaction modalities, performance environments and learner modeling data sources. Additionally, each of the GIFT modules (including Domain and Pedagogical) are separable within the Framework, meaning that different instructional approaches, or domains of instantiation can be implemented within the same framework.

Specifically, the current version of GIFT handles domain representations inside of a Domain Module, configured by an object called a Domain Knowledge File (DKF). With this object, domains can be organized as a series of Tasks, Concepts, and Conditions. The DKF also references or -contains assessment logic for use with a training application, such as a virtual environment application. GIFT uses the DKF configured Domain Module in order to communicate changes in learner states, which may be based on cognitive, affective, or performance data gathered from the learner. The Domain Module can provide responses to micro-adaptive instructional strategies from the pedagogical engine in response to those learner state transitions in the form of feedback and/or training scenario adaptations. DKF files can be reused within GIFT, and new DKF files can be configured via GIFT's authoring tools.

In addition to the domain model and its ITS complements, a number of additional elements support real-world tutoring and are integral to the overall strategy for GIFT. Those elements are *architecture*— the technological backbone of the ITS, *authoring*— the tools and systems that enable the creation of the ITS, and *analysis*— those processes (including experimentation) that serve to evaluate the effectiveness of training system configurations. Creating a more robust domain module in support of military tasks potentially adds complexity to each of these elements. While such complexity may be expected in software engineering or scientific measurement, complexity is a significant threat to *authoring*.

One of the primary goals for GIFT is to reduce the time and skill required to author and assesses adaptive tutors (Sottilare & Gilbert, 2011). However, ITS authoring is an area in which persons with limited programming experience (e.g., instructors, subject matter experts) may be responsible for the creation and management of adaptive tutors. Even the *concept* of authoring an adaptive tutor represents a new content creation activity, the current state of which is characterized by a series of tradeoffs between *usability*, *depth*, and *flexibility* (Murray, 2004). Research will be needed to determine appropriate levels of domain model transparency and the appropriate level of author-control over its configuration.

In an effort to address authoring complexity in GIFT, for example, we are developing GUI-based tools to semi-automate the authoring process. These revised authoring tools are intended to provide usable interfaces to authors without the requirement to write computer code. Through continuous development, we intend to further improve the authoring experience by leveraging best practices in experience design to promote learnability. For instance, authoring templates can be used to increase efficiency, and the progressive disclosure of authoring tool functions / interfaces can help to promote learnability of the authoring system (Lightbown, 2015). Alternatively, advances in ITS *architecture* may eventually enable near full-automation of tutor authoring, though this effort should be viewed as a parallel option to, not a replacement for, user-generated tutors.

The intelligent tutor is a system of interconnected models, supported by elements that enable its functionality. In practice, it is important to consider how advances in the domain module will impact the other system components, and how the demands of complex domains, such as military tasks, impact design and implementation requirements at the system-level.

4. CONCLUSIONS

Many military tasks are hybrids of task domains in that they include aspects of cognitive (thinking – evaluating, problem-solving, and decision-making), affective (feeling – making value judgments), psychomotor (doing – physical action), and/or social (collaborating – working in teams). Military training differs greatly from traditional ITSs which are primarily problem-based (e.g., mathematics, physics, computer programming) and generally vary only in complexity. Given much of military training is scenario-based, the realism of the training environment, accessibility of the training, the complexity of the scenario, the physical dynamics of the task, and the variable level of definition are all design considerations for adaptive training systems for military use. It will be essential to match the attributes of the environment to the task domain by asking the question "what is necessary to train the task effectively". This variability in adaptive training and educational domains will allow for greater opportunities for military personnel to train at the point-of-need and to train more closely to how they fight. This is anticipated to result in greater learning, performance, retention, and transfer of skills to the operational environment.

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OPTIMALLY LOCATING SURVEILLANCE ASSETS IN URBAN AREAS

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ABSTRACT
This paper develops mathematical-programming models for optimal placement of tower-mounted surveillance systems such as BETSS-C (Base Expeditionary Targeting and Surveillance Systems-Combined). A solution maximizes the "value" that a set of tower-mounted cameras has in covering pre-defined "points of interest" on the ground. Near-optimal solutions for problems with up to 20 towers, 30 candidate locations for those towers and 100 points of interest are produced on laptop computer in under five minutes.

Keywords: camera tower, surveillance, facility location, integer programming, generalized network flow

1. INTRODUCTION
In Iraq and Afghanistan, Coalition Forces have found that camera towers such as "GBOSS" (Ground-Based Operational Surveillance System), BETSS-C (Base Expeditionary Targeting and Surveillance Systems-Combined), and JLENS/RAID PS2 systems can help thwart the emplacement of improvised explosive devices (IEDs). These systems can also identify disturbances to which troops should respond, follow suspicious vehicles, and so on. Their use in populated areas is critical to the security of U.S. and allied military forces as well as local civilian populations. No tool currently exists, however, for assigning a limited number of camera towers to a larger number of potential (secure) sites so as to optimize the "value" of the surveilled "points of interest" (POIs) or to optimize some other appropriate objective.
To address the lack of an appropriate analysis tool, the research described here develops, implements and solves a series of prototypic mathematical models for optimizing camera-tower placement. We create mixed-integer, nonlinear optimization (MINLP) models for this purpose, reformulate those models for tractability, and solve them using general-purpose optimization tools. Results are displayed graphically. We note that the models described in this paper should apply to the optimized placement of aerostats (i.e., tethered, camera-carrying balloons), in conjunction with camera towers or by themselves.

2. MATHEMATICAL MODELS

2.1. A Basic Camera-Tower-Location Model
We first develop a MINLP model for optimizing camera-tower locations. This model, and the others studied in this paper, concern themselves with detecting specific acts at specific points on the ground from individual towers, and not with attempting to identify and track suspicious, moving targets, perhaps across multiple towers. Thus, our models resemble stochastic facility-location models in which a limited set of facilities is opened to serve uncertain customer demands at known locations. Analysts use such models for locating and sizing actual production facilities, but also for locating emergency-services facilities (such as fire stations) and delivery assets (such as ambulances) to meet probabilistically occurring emergencies (such as building fires or medical calls). Snyder (2006) provides a review of such models.
Murray et al. (2006) make explicit use variants on facility-location models in order to locate security monitors effectively. Their bi-objective approach locates cameras (cf. facilities) and accumulates rewards for both single and double coverage of a control point (cf. customer). Their approach does not incorporate compounded probabilities of detection as our models do, however. Hörster and R. Lienhart (2006) address a problem involving both coverage and resolution of images, accounting for cost of operations and effectiveness of a set of orientation-dependent cameras. They have a number of models, but at least one model has a strong flavor of a facility-location model, with variables that determine whether a camera is placed at particular location and with a particular orientation (cf. facility operations), and with rewards that depend on whether a particular control point is covered by (cf. served by) by a camera. Bodor et al. (2007) address the problem of camera placement for maximum observability of moving subjects in a given area, and introduce a joint measure of observability with quality of the view. Their optimization in terms of the "motion statistics of a scene" resembles the optimization of facility locations over an empirical distribution of customer demands. A substantial literature covers more detailed models of camera physics and subject motion but, of necessity, limits the combinatorial aspects of camera placement. For an overview of such models, we refer the reader to Section 3 in Bodor et al. (2007) and the references therein.
Our models are not game-theoretic defender-attacker models (Brown et al. 2006), but is useful to describe them in terms of (a) a *defender* who operates the surveillance system and who will suffer the consequences of undetected attacks, and (b) an *attacker* who attempts to carry out attacks on the defender in a probabilistic fashion. Our first model, **NLPavg1**, follows.

$$\textbf{NLPavg1}: \min_{\mathbf{y}} \sum_{i \in I} v_i \prod_{\ell \in L} q_{i\ell}^{y_\ell} \quad (1)$$

subject to:

$$\sum_{\ell \in L} y_\ell \le m \quad (2)$$

$$y_l \in \{0,1\} \forall l \in L, \quad (3)$$

where $\ell \in L$ is a set of potential camera-tower locations; $i \in I$ is a set of POIs that should be kept under surveillance; m is the number of camera towers available, with each having identical capabilities; v_i is the "value" of POI *i*, which represents the damage that the unique "initiating event" (such as an IED emplacement) would cause at i if the event is not detected; $q_{i\ell}$ is the probability of not detecting an event at POI *i* from location ℓ if a tower is placed at that location; and the decision variable $y_\ell = 1$ if a tower is located at ℓ, and $y_\ell = 0$ otherwise. If more than one type of event might occur a POI i (e.g., an IED emplacement or a riot), the POI can be replicated and treated as a separate POI for each event type.

We note that, as described above, each event occurs or does not occur within short timeframe. We maintain that viewpoint for simplicity in descriptions. A surveillance system might be in place for months or years, however, and a POI might suffer from many events over that time. In such a case, the model remains valid, however, if events at i occur according to a Poisson process with known rate (Lin et al. 2013). Now, v_i represents the expected total value of potential attacks on i over the monitoring period if all attacks are successful.

Now, since $\prod_{\ell \in L} q_{i\ell}^{y_\ell}$ is the probability that an event at at POI *i* goes undetected by all of the installed camera towers, **NLPavg1**'s objective, under an assumption of independence, minimizes overall expected value of undetected events across all POIs, subject to the limit on available towers. Henceforth, we use "expected damage" to mean the "expected value of undetected events." In particular, we refer to "expected damage at an individual POI *i*," $v_i \prod_{\ell \in L} q_{i\ell}^{y_\ell}$, and to "overall expected damage," $\sum_{i \in I} v_i \prod_{\ell \in L} q_{i\ell}^{y_\ell}$. We add four notes, also:

(1) **NLPavg1** does assume independence of detections for an event at a given POI, and requires some user inputs that may not be immediately available, namely v_i and $q_{i\ell}$; subjective estimates for these quantities may be required.

(2) The notation hides some of the practical aspects of an implementation. Suppose, for instance, that no line of sight exists between potential camera-tower location ℓ and POI *i*. In this case $q_{i\ell} = 1$ and the model is correct. However, our implementation would not even create the corresponding term in the objective function.

(3) This model and all others in this paper extend in a straightforward fashion to handle various (but fixed) camera configurations at a given location that provide different coverages of an area.

(4) Given that $v_i > 0 \ \forall i$, and given that $\prod_{\ell \in L} q_{i\ell}^{y_\ell}$ is a convex function of continuous y_i, the continuous relaxation of **NLPavg1** is a convex problem. Thus, in theory, **NLPavg1** can be solved using the integer extension of Kelley's cutting-plane algorithm "KCPA"; see Kelley (1960). Our testing of KCPA shows that it performs poorly, however. We have also tested a standard solver that will solve convex MINLPs like **NLPavg1**. Again, computational performance is poor. (Some details will be provided in Section 4.) Because of poor results with "standard methods," we emphasize the conversion of **NLPavg1** as well the next model, into mixed-integer linear programs (MIPs), which can be solved by standard, linear-programming-based branch and bound.

2.2. Minimizing Maximum Expected Damage

A second model, **NLPmx1**, seeks to minimize the maximum expected damage at any POI, i.e., the worst-case damage across all POIs:

$$\textbf{NLPmx1}: \min_{\mathbf{y},z} z \quad (4)$$

subject to: (2), (3)

$$z \ge v_i \prod_{\ell \in L} q_{i\ell}^{y_\ell} \qquad \forall i \in I, \quad (5)$$

where the new set of constraints ensures that the objective value takes the maximum, across all POIs, of the expected damage at each individual POI. In theory, **NLPmx1** can also be solved via an extension Kelley's cutting-plane algorithm, but a simpler approach exists based on the fact that we can minimize z' = log z without affecting the outcome:

$$\log z \ge \log\left(v_i \prod_{\ell \in L} q_{i\ell}^{y_\ell} \right) \forall i \in I \Rightarrow$$

$$z' \ge \log v_i + \sum_{l \in L} \left(\log q_{il} \right) y_l \ \forall i \in I. \quad (6)$$

Thus, the following model is equivalent to **NLPmx1**, and can be solved as a MIP:

$$\textbf{MIPmx1}: \min_{\mathbf{y},z'} z' \quad (7)$$

subject to:

(2), (3), (6).

NLPmx1 may be a more appropriate model than **NLPavg1** if, roughly speaking, a large number of small-scale attacks spread across a region is deemed less damaging to the defender than a few large-scale attacks that are focused on a smaller area. For example, minimizing overall expected damage seems appropriate when the attacker has limited information about our monitoring methods and our valuations of the various POIs: we expect an adversary or group of adversaries to carry out multiple, somewhat "random" attacks in this case. A worst-case analysis could be more appropriate if the attacker can learn about and selectively attack a few high-value and possibly poorly monitored locations; this relates to defender-attacker models as described by Brown et al. (2006).

Unfortunately, the linearization technique applied to **NLPmx1** does not apply to **NLPavg1**: the logarithm function cannot be used to decompose that model's objective function $\sum_{i\in I} v_i \prod_{\ell\in L} q_{i\ell}^{y_\ell}$ into a linear expression of the *y*-variables. Different linearization techniques apply, however, as described next.

2.3. Converting NLPavg1 into Generalized Network Flow Based Model

This section converts **NLPavg1** into a MIP whose structure may be viewed in terms of generalized network flows (Ahuja et al., 1993, pp. 566-572). Let $L_i = \{\ell \in L \mid q_{i\ell} < 1\}$, let $n(i) = |L_i|$, and assume that L_i is ordered as $L_i = \{\ell_i^1, \ell_i^2, \ldots, \ell_i^k, \ldots \ell_i^{n(i)}\}$. We propose the following model:

NETavg1: $$\min_{\mathbf{q}',\mathbf{x},\bar{\mathbf{x}},\mathbf{y}} \sum_{i\in I} v_i q_i' \quad (8)$$

subject to:

(2), (3)

$$x_{i,\ell_i^1} + \bar{x}_{i,\ell_i^1} = 1 \qquad \forall i \in I \quad (9)$$

$$x_{i\ell_i^k} + \bar{x}_{i\ell_i^k} = x_{i,\ell_i^{k-1}} + q_{i,\ell_i^{k-1}}\, \bar{x}_{i,\ell_i^{k-1}} \quad \forall i \in I,\ k = 2,\ldots,n(i) \quad (10)$$

$$q_i' = x_{i,\ell_i^{n(i)}} + q_{i,\ell_i^{n(i)}}\, \bar{x}_{i,\ell_i^{n(i)}} \quad \forall i \in I \quad (11)$$

$$0 \le x_{i\ell} \le 1 - y_\ell \qquad \forall i \in I, \ell \in L_i \quad (12)$$

$$0 \le \bar{x}_{i\ell} \le y_\ell \qquad \forall i \in I, \ell \in L_i. \quad (13)$$

For each $i \in I$, the model describes a generalized network flow over a series of paired, parallel arcs. Starting with one unit of flow representing the probability of non-detection of an event at i, the flow first crosses one of two parallel arcs corresponding to $\ell_i^1 \in L_i$. If $y_{\ell_i^1} = 0$, no camera tower is installed at ℓ_i^1, an event at *i* cannot be detected from that location, and the flow traverses the arc corresponding to $x_{i\ell_i^1}$ with no reduction; that is, the probability of non-detection remains one. But, if $y_{\ell_i^1} = 1$, the flow traverses an arc corresponding to $\bar{x}_{i\ell_i^1}$, and the flow received at the end of that arc is reduced to $q_{i\ell_i^1}$; that is, the probability of non-detection of an event at i has been reduced from one to that factor. Repeating this construction for all $\ell_i^k, k = 2,...,n(i),$ means that the flow exiting the last node associated with i and recorded by q_i' equals $\prod_{k=1}^{n(i)} q_{i\ell_i^k}^{y_{\ell_i^k}}$, as required.

2.4. Limited Camera Surveillance

The models **NLPavg1, NETavg1** and **MIPmx1** all assume that if $q_{i\ell} < 1$ and a camera tower is located at ℓ, then a probability of non-detection equaling $q_{i\ell}$ is always achieved from that location. This assumption may be optimistic, because a camera needs time to pan or rotate, tilt, zoom in and out, and focus on each of the POIs assigned to it (Peruzzi 2013). Also, human observers may become less efficient (i.e., probabilities of detection may decrease) if required to monitor too many POIs. Our research has not yet addressed directly these difficult issues, although the work of Burton et al. (2008) may apply. That work determines the proportion of time that a single camera should dedicate to surveilling POI *i*, assuming events of interest occur according to a Poisson process with a location-dependent rate and that detection times at each location are exponentially distributed. (Independence is assumed between POIs.)

We can make our approach more realistic with respect to the issues discussed above, however. To do that, we incorporate a parameter *k* denoting the maximum number of sites that any one camera tower may be assigned to surveil. Additional variables are also defined: $\bar{y}_{i\ell} = 1$ if a tower is located at $\ell \in L$ and is assigned to surveil POI $i \in I$, and $\bar{y}_{i\ell} = 0$, otherwise. With this new modeling paradigm, **NLPavg1, NETavg1** and **MIPmx1** convert into **NLPavg2, NETavg2** and **MIPmx2**, respectively:

NLPavg2: $$\min_{\mathbf{y},\bar{\mathbf{y}}} \sum_{i\in I} v_i \prod_{\ell\in L} q_{i\ell}^{\bar{y}_{i\ell}} \quad (14)$$

subject to:

(2), (3)

$$\sum_{i\in I} \bar{y}_{i\ell} \le k\, y_\ell \qquad \forall \ell \in L \quad (15)$$

NETavg2: $$\min_{\mathbf{q}',\mathbf{x},\bar{\mathbf{x}},\mathbf{y},\bar{\mathbf{y}}} \sum_{i\in I} v_i q_i' \quad (16)$$

subject to:

(2), (3), (9)-(13),(15)

$$0 \le x_{i\ell} \le 1 - \bar{y}_{i\ell} \qquad \forall i \in I, \ell \in L_i \quad (17)$$

$$0 \le \bar{x}_{i\ell} \le \bar{y}_{i\ell} \qquad \forall i \in I, \ell \in L_i \ ; \quad (18)$$

MIPmx2: $$\min_{\mathbf{x},\bar{\mathbf{x}},\mathbf{y},\bar{\mathbf{y}},z'} z' \quad (19)$$

subject to:

(2), (3), (15)

$$z' \ge \log v_i + \sum_{\ell\in L} (\log q_{i\ell}) \bar{y}_{i\ell} \quad \forall i \in I. \quad (20)$$

3. COMPUTATIONAL IMPLEMENTATION

3.1. Optimization Environments

This section tests **NETavg1, MIPmx1, NETavg2** and **MIPmx2** using a number of randomly generated

physical settings. All linear models are implemented in Xpress-MP development environment (FICO 2015), and are solved using the Xpress Optimizer, Version 27.01.02. The remainder of the document refers to this implementation, except for brief, specific comments on results obtained using (a) Kelley's cutting plane algorithm on a nonlinear formulation, and (b) one standard algorithm for MINLPs.
The size of the mathematical models varies by scenario (see Section 4). For example, scenario "*Large*9," which applies **NETavg2** on a 30-location, 100-POI example, generates a model with 2,738 variables (899 binary) and 2,739 constraints; scenario "*Large*10," which is identical to "*Large*9," but applies **MIPmx2**, generates a model with 900 variables (899 binary) and 131 constraints. All computational times are for runs performed using a single processor on a Dell Latitude XT2 Core Duo laptop computer, with 5 GB of RAM, and running at 1.60 GHz.

3.2. Database

The supporting database for our tool is implemented in Microsoft Access (Microsoft 2015). Each database file contains one modeling example (corresponding to the "DBQ" input parameter in the Xpress-MP code), which represents an instance of physical layout of POIs and locations. For that instance, the file may include several "scenario" settings that differ, for example, in the number of available cameras or in the type of model to be solved. The structure of this database is as follows (see Figure 1):
Tables: LOC (locations); POI (points of interest); LOC_POI (attributes for locations and points of interest); SCENARIO (different scenarios to run, see Section 4, and associated solutions to store, for the incumbent "example," of locations and POIs).
Queries: Delete_LOC (eliminates all records from LOC table); Delete_POI (eliminates all records from POI table); LOC_POI_CreateMatrix (creates the list of all possible combinations of locations and POIs to ease the input of associated probabilities).

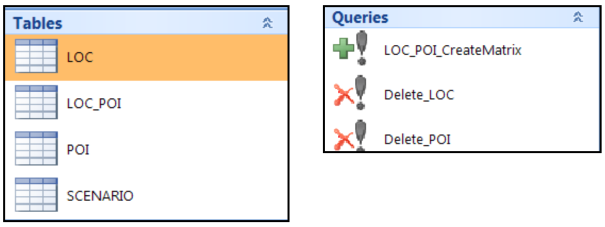

Figure 1. Database tables and queries

Fields in each of the above tables and relationships are shown in Figure 2. Tables 1-4 describe these fields in more detail.

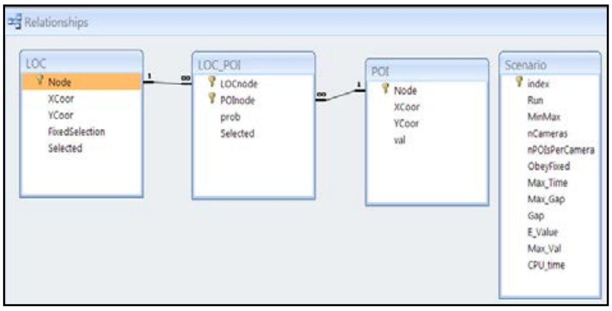

Figure 2. Fields for the database tables, and relationships among tables

Table 1: LOC (Candidate tower locations)

Name	**Type**	**Default**	**Description**
Node	Text		Location code
XCoor	Double	0.0	X coordinate
YCoor	Double	0.0	Y coordinate
FixedSelection	Yes/No	No	Location must be selected?
Selected	Yes/No	No	Location was selected? (OUTPUT)

Table 2: POI (Points of interest)

Name	**Type**	**Default**	**Description**
Node	Text		POI code
XCoor	Double	0.0	X coordinate
YCoor	Double	0.0	Y coordinate
val	Double	1.0	Value of the POI

Table 3: LOC_POI (Attributes by LOC and POI)

Name	**Type**	**Default**	**Description**
LOCnode	Text		Location code
POInode	Text		POI code
prob	Double	0.0	Probability of detection at the POI from the location
Selected	Yes/No	No	POI selected to be surveilled from the location? (OUTPUT)

Table 4: SCENARIO (Parameters, options, etc.)

Name	Type	Default	Description
Index	Long Integer		Scenario index (AUTOMATED)
Run	Yes/No	Yes	Run this scenario?
MinMax	Yes/No	No	Solve **MIPmx** (Yes) or **NETavg** (No). (Variants **1** or **2** depending on the number of POIs per camera)
nCameras	Long Integer	0	Number of camera towers allowed
nPOIsPerCamera	Double	2	Number of POIs each camera tower may surveil at a time. Enter 0 if unlimited.
ObeyFixed	Yes/No	No	Obey all fixed selections specified in LOC table?
Max_Time	Long Integer	100	Maximum run time (seconds)?
Max_Gap	Double	0.0	Maximum optimality gap?
Gap	Double		Actual gap? (OUTPUT)
E_Value	Double		Overall expected damage? (OUTPUT)
Max_Val	Double		Maximum single damage? (OUTPUT)
CPU_time	Double		Computational time (seconds)? (OUTPUT)

3.3. Graphical Input and Output Environment

Xpress-MP's embedded graphical displays help visualize the problem and its solution. For example, Figure 3 shows a snapshot mapping out POIs and candidate camera-tower locations; the values for POIs are displayed, also. By clicking on the "Visible" toggle, we would see a series of lines connecting candidate locations with those POIs that could be surveilled, with strictly positive probability of detection.

After the model is run, the "Selected" toggle turns on the display of the following: (a) optimized tower locations, (b) the type of model solved, i.e., average ("avg") or min-max ("mx"), and (c) the number of camera towers available. "Sel. Visible" (Selected Visible) toggles a display that shows which camera towers are assigned to which POIs.

4. COMPUTATIONAL RESULTS

This section presents results for two hypothetical examples, "Small Example" and "Large Example." Each example has a specific "physical setting," which connotes geographical data on candidate locations and POIs, POI values, and probabilities of event detection by POI and location.

An example may also have several parametric variants called "scenarios." A scenario includes the original physical setting from the example, but adds certain parameter values and chooses which optimization model to apply. For instance, we can use the geographical layout of Small Example and create one scenario that allows more camera towers than another, or that seeks to optimize **NETavg1** rather than, say, **MIPmx1**. The scenario is completed by filling in the data for the scenario record (for example, see, Figure 5 in Section 4.1). A user can create a rich variety of scenarios for the same example by just changing a few input parameters and/or toggle settings as identified in Table 4. For example, the user can set the number of camera towers available, toggle the use an ``mx model'' or an "avg model." and specify solution-algorithm parameters (e.g., maximum run time allowed).

Unless otherwise noted, all the scenarios are set to run until a 0% optimality gap is achieved, or a maximum time limit of 300 seconds is reached. No locations are preselected to receive a camera tower.

4.1. Small Example

The physical layout in this example (Figure 3) has ten potential camera-tower locations and eight POIs. Figure 4 enlarges a portion of the example with visibility links activated and associated probabilities of detection displayed. For example, the probability of detecting POI I4 from location L8 is 0.707.

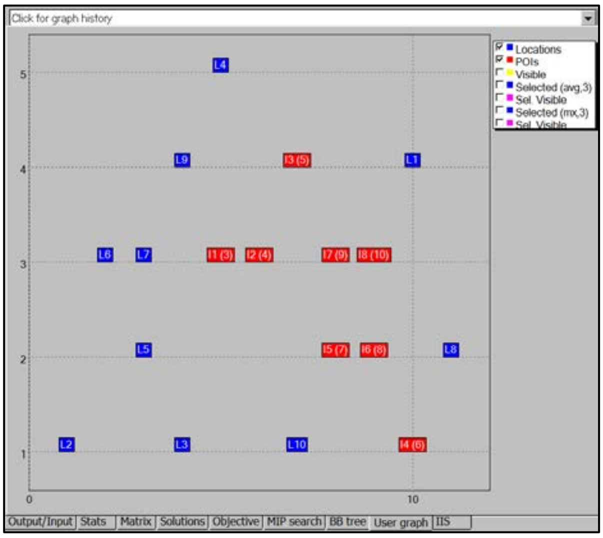

Figure 3. Preliminary display of locations (blue) and POIs (red)

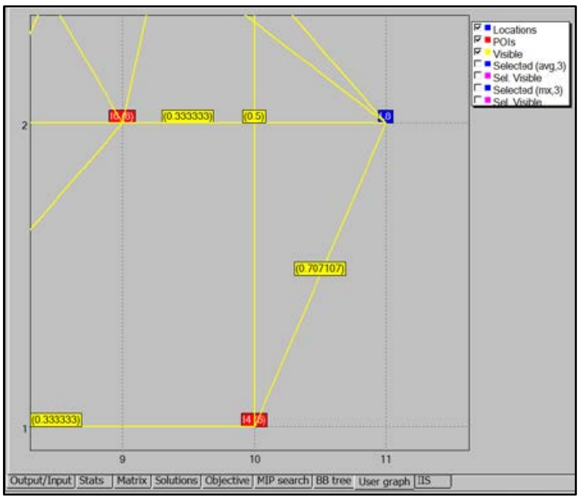

Figure 4. A portion of Small Example enlarged to show lines of sight, two POIs and one camera-tower location.

We run four scenarios for this example, as indicated in Figure 5. (From here on, we use *Small*n to refer to the n-th scenario for Small Example, where the index n is automatically produced by the database program.) *Small*1, as modeled and solved, seeks to minimize overall expected damage by applying **NETavg1**. Each of three available camera towers can surveil an unlimited number of POIs simultaneously (indicated with a default value of zero in the data). *Small*2 is identical to *Small*1, but a different model, **MIPmx1,** applies; that is, we seek to minimize the maximum damage at any individual POI. *Small*3 and *Small*4 are identical to *Small*1 and *Small*2, respectively, except that they limit the number of POIs that can be surveilled from any one location to a maximum of three. Accordingly, we apply **NETavg2** to solve *Small*3 and **MIPmx2** to solve *Small*4.

SCENARIO

index	Run	MinMax	nCameras	nPOIsPerCamera	ObeyFixed	Max_Time	Max_Gap
1	☑	☐	3	0	☐	300	0
2	☑	☑	3	0	☐	300	0
3	☑	☐	3	3	☐	300	0
4	☑	☑	3	3	☐	300	0

Figure 5. Small Example scenarios (*Small*1,...,*Small*4)

Figure 6 summarizes results for the Small Example scenarios. *Small*1 and *Small*2 produce similar solutions: the optimal *Small*1 objective (for **NETavg1**) yields an expected damage, over all POIs, of 11.15; see "E_Value" output. Here, the largest, expected damage for a single POI is 1.94, as seen under "Max_Val." In fact, this is the minimum Max_Val achievable, as shown when model **MIPmx1** is applied in *Small*2. By coincidence, the converse occurs in this example: the E_Value in the *Small*2 solution matches the minimum E_Value obtained for *Small*1. (This coincidence seems unlikely, in general, because instances of **MIPmx1** may have many optimal solutions.)

SCENARIO

index	Run	MinMax	nCameras	nPOIsPerCamera	Gap	E_Value	Max_Val	CPU_time
1	☑	☐	3	0	0.00	11.15	1.94	0.06
2	☑	☑	3	0	0.00	11.15	1.94	0.01
3	☑	☐	3	3	0.00	20.60	5.00	0.08
4	☑	☑	3	3	0.00	20.89	3.40	0.06

Figure 6. Results for Small Example scenarios

Scenarios *Small*3 and *Small*4 are restrictions of *Small*1 and *Small*2, respectively. E_Value for *Small*3 increase to 20.60 from *Small*1's value of 11.15, and "Max-Value" increases for *Small*4 to 3.40 from Small2's value of 1.94. Figure 8 displays the solutions. We observe that **NETavg2**'s solution leaves two POIs without any surveillance in *Small*3, and one of those unsurveilled POIs (I3) defines the maximum expected damage (Max_Val equals 5.0). On the other hand, when Max_Val is minimized using **MIPmx2** in *Small*4, the largest, expected damage occurs at another POI (I7, with Max_Val equaling 3.4).

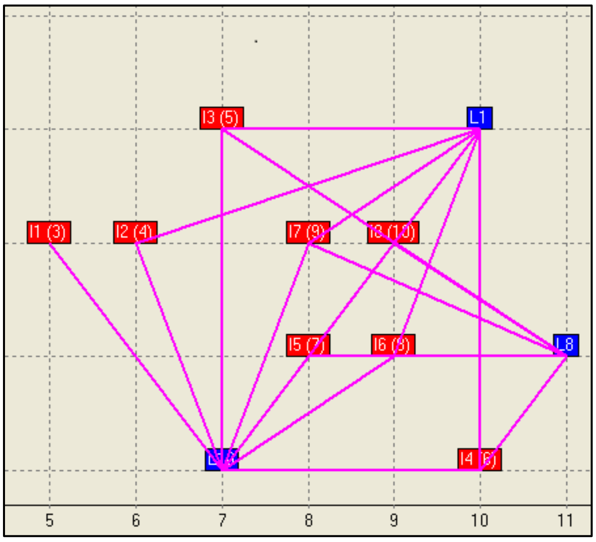

Figure 7. Graphical solution to both *Small*1 and *Small*2 scenarios.

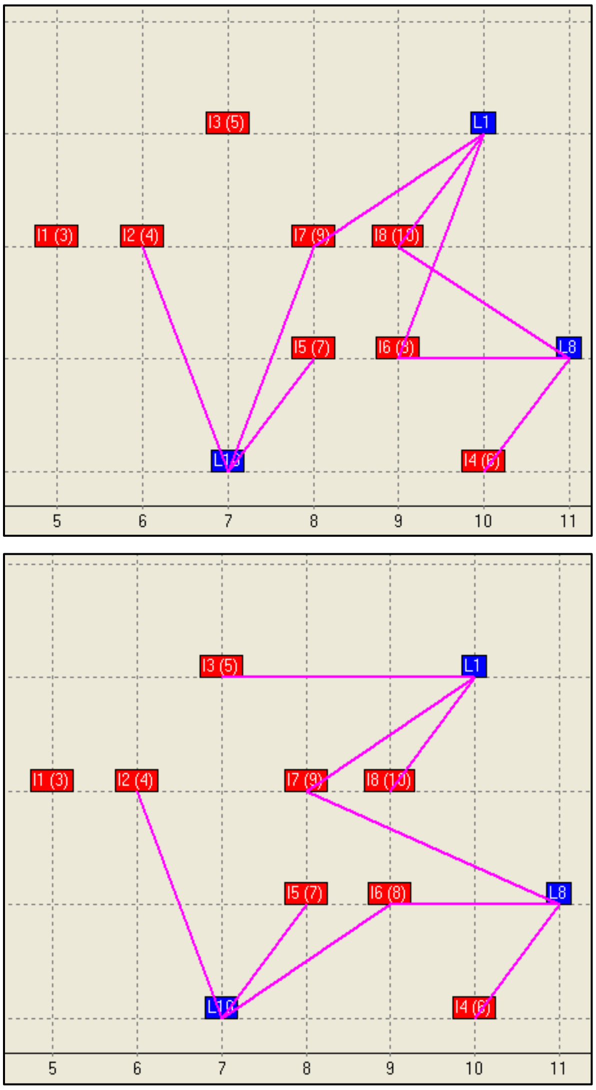

Figure 8. Graphical solutions to *Small*4 (top) and *Small*4 (bottom) scenarios

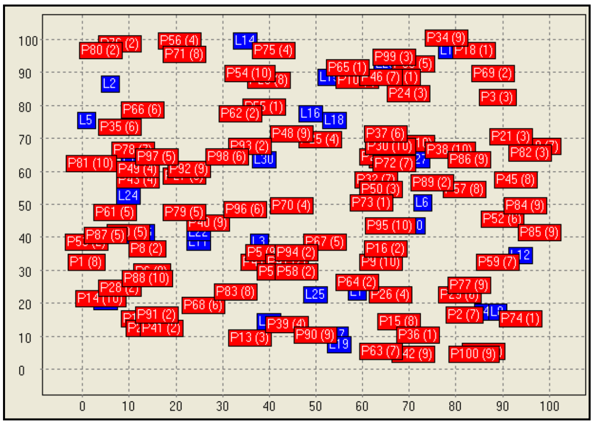

Figure 9. Large Example with 30 locations and 100 POIs

index	Run	MinMax	nCameras	nPOIsPerCamera	ObeyFixed	Max_Time	Max_Gap
1	✓		5	0		300	0
2	✓		10	0		300	0
3	✓		15	0		300	0
4	✓		20	0		300	0
5	✓		25	0		300	0
6	✓		15	2		300	0
7	✓		15	4		300	0
8	✓		15	6		300	0
9	✓		15	8		300	0
10	✓	✓	15	8		300	0

Figure 10. Large Example scenarios (*Large*1,..., *Large*10)

index	Run	MinMax	nCameras	nPOIsPerCamera	Gap	E_Value	Max_Val	CPU_time
1	✓		5	0	0.00	179.27	9.00	8.89
2	✓		10	0	0.00	66.88	5.64	120.38
3	✓		15	0	0.00	28.01	2.55	177.18
4	✓		20	0	0.00	13.16	2.19	17.46
5	✓		25	0	0.00	8.58	2.19	2.36
6	✓		15	2	0.00	298.84	9.00	0.76
7	✓		15	4	0.00	162.12	7.00	10.00
8	✓		15	6	0.02	96.59	5.00	300.20
9	✓		15	8	0.14	66.13	4.89	299.77
10	✓	✓	15	8	0.00	124.04	2.19	3.36

Figure 11. Results for Large Example scenarios

4.2. Large Example

This example has 100 POIs to be surveilled from some subset of 30 candidate camera-tower locations (Figure 9). We run ten scenarios, *Large*1,...,*Large*10 (see Figure 10): *Large*1-*Large*5 use **NETavg1** to allocate 5, 10, 15, 20 or 25 towers, respectively, with unlimited surveillance for each tower; *Large*6-*Large*9 fix the number of available camera towers to 15, and solve **NETavg2** with per-tower surveillance limits of 2, 4, 6 and 8 POIs, respectively; *Large*10 solves the 15-tower, 8-POIs-per-tower problem using **MIPmx2**.

Figure 11 displays results. We note, for example, that all unlimited-surveillance scenarios solve optimally in the allotted time. This is not the case for *Large*8 and *Large*9 limited-surveillance scenarios, where 2% and 14% optimality gaps remain after 300 seconds of computation.

On the other hand, *Large*10 solves quickly. Recall that *Large*10 is identical to *Large*9, except that *Large*10 minimizes the largest expected damage for a single POI (Max_Value), while *Large*9 minimizes overall expected damage (E_Value). Outcomes are notably different for *Large*9 and *Large*10. In particular, Max_Value is over 100% greater (worse) for *Large*9 than for *Large*10 and, conversely, E_Value for *Large*10 is almost 100% greater (worse) than for *Large*9.

Figure 12 graphically depicts the solutions for the two scenarios. (POI names are hidden in the displays for the sake of clarity.) We observe that, for the most part, the scenario solutions place camera towers at different locations. But, when a location such as L27 at coordinates (72, 61) is selected under both scenarios, the surveilled POIs are different.

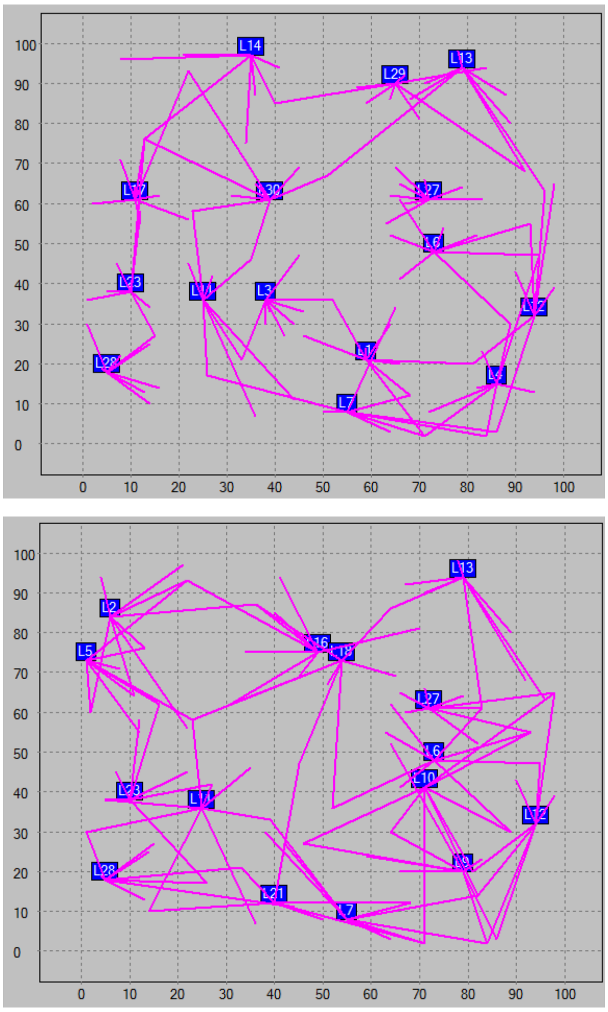

Figure 12. Graphical solution displays for scenarios *Large*9 (top) and *Large*10 (bottom).

As discussed in Section 2.1, it is possible, in theory, to solve **NLPavg1** and **NLPavg2** using (a) variants of KCPA (Kelley 1960) and (b) a standard MINLP solver. We have implemented (a) and (b) for our Small- and Large-Example scenarios using the GAMS algebraic modeling system (McCarl et al. 2014). Specifically, we use CPLEX 12.4 (GAMS 2015, pp. 109-160) to solve master problems in our own implementation of KCPA, and we use DICOPT (GAMS 2015, pp. 189-208) as a general MINLP solver; our implementation of DICOPT employs CPLEX 12.4 for solving MIP master problems and MINOS (GAMS 2015, pp. 323-354) to solve continuous, non-linear subproblems.

For Small-Example scenarios, DICOPT and KCPA produce optimal solutions in times that are comparable to, or only modestly longer than, those reported in Figure 6. On the other hand, with a few exceptions, neither DICOPT nor KCPA solve Large-Example scenarios efficiently. For example, DICOPT solves *Large1*, which is the smallest of the Large-Example scenarios, in only 2 seconds, but it produces a suboptimal solution having an E_Value of 203.27, rather than an optimal solution, which has an optimal E_Value of 179.27. Relative optimality gaps become even worse as the complexity of the scenarios increases. For example, *Large*9 results in an E_Value equaling 138.30, yet the optimal value is 66.13. Finally, we note that KCPA converges to the optimal solution of the scenarios mentioned above, but even the smallest scenario takes hundreds of iterations to solve and requires computation time that exceeds 1,900 seconds.

5. CONCLUSIONS AND FUTURE RESEARCH

Our work should be extended to more accurately assess and incorporate the "information value" of a collection of POIs that might be assigned to one or more camera towers for surveillance. Exactly how to carry this out is unclear, but we see three key issues:

(a) The current implementation assumes a simple additive or separable value function that ignores "scheduling issues." But, a camera that is set to surveil a collection of POIs may be programmed to focus on, zoom in on, and surveil each POI for a given amount of time before transitioning to another POI. The corresponding surveillance and transition times affect the value of the information collected (for example, the probability that an IED emplacement is detected), and should be part of the optimization process.

(b) Our current models assume constant conditions, but the time of day and weather can affect probabilities of event detection. Naturally, this variability could influence optimal camera-tower placements.

(c) We ignore the possibility that mobile surveillance systems such as UAVs may operate in conjunction with camera towers.

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DEFENSE AND FIRST-RESPONDERS LEVERAGE VIRTUAL TECHNOLOGY: TAKING IT TO THE EDGE

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ABSTRACT
Active-shooter incidents with multiple well-coordinated perpetrators are becoming more common worldwide. This concern inspired the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) First Responder's Group (FRG) to build a partnership with the U.S. Army Research Laboratory - Human Research and Engineering Directorate, Simulation and Training Technology Center (ARL-HRED STTC) who has extensive experience making use of technology to improve training. First responders from Sacramento, California came together to establish the detailed requirements. This cross-organization partnership developed a virtual prototype for training first responders, which was successfully demonstrated in Sacramento in fiscal year 2014. This led the way for inter-departmental and cross-discipline groups to train together in advance of an attack to improve coordination and reduce response time and casualties. This paper illustrates how the organizations conducted a training exercise to support flexible training tactics and scenarios to maintain readiness despite limited resources.

Keywords: First Responders, Virtual Training Technology, Cross Collaboration, EDGE

1. INTRODUCTION

Consider your most recent stay in a hotel or visit to a mall. What would happen if you suddenly heard and felt an explosion, then gunfire, and in the ensuing chaos, you watched people all around you; men, women and children injured or killed by the blast, being taken hostage or being gunned down? In the distance, you hear other explosions and instinctively know this isn't an isolated incident and that help may arrive soon. You hear and see individuals speaking a foreign language with automatic weapons randomly shooting while you try to stay out of sight. One of the shooters begins setting fires along the exits to herd people toward the other shooters. You hear sirens, but with the fire and the active-shooters, you don't know what to expect; once the first responders coordinate their efforts and make their way into the building, will it be too late?

Now imagine you are the first Law Enforcement (LE) officer on the scene. There is carnage, fire, people screaming, and the sound of gunshots and shouting coming from multiple locations. This is clearly a "high complexity" event, meaning that it involves "teams of trained attackers simultaneously attacking multiple locations" (Blair, Nichols, Burns, & Curnutt, 2013). Based on historical data (Blair, Nichols, Burns, & Curnutt, 2013), if shooting is active at the time LE arrives, "there is a 14 percent chance that an officer will be shot when he or she makes a solo entry into an active-shooter attack site" (FBI Law Enforcement Bulletin, 2014), other sources show the statistic as closer to 15%, making response to an Active Shooter Event (ASE) one of the most dangerous activities in LE. The decision to proceed is a weighty one. The most critical task during an ASE is to "stop the killing" (Blair, Nichols, Burns, & Curnutt, 2013), so LE cannot sit idly while pondering the best course of action. The first LE officer on the scene has the command role and must coordinate the entire response until a higher authority takes over, meaning he or she holds responsibility for the scene. This means moving forward to stop the threat while coordinating with the fire department, immediately.

Fire and Emergency Medical Services (EMS) considers an event described above as an Active Shooter and Mass Casualty Incident (AS/MCI) (Federal Emergency Management Agency (FEMA) U.S. Fire Administration, 2013). The term describes active shooter incidents as those "involving one or more subjects that participate in a random or systematic shooting spree, demonstrating their intent to continuously harm others" (Federal Emergency Management Agency (FEMA) U.S. Fire Administration, 2013). The term is focused on fire/rescue and EMS agencies. AS/MCIs are primary LE events that require coordination between the LE on-scene lead and the fire/rescue/EMS on-scene lead. Unified Command (UC) is the vehicle for command and control of the event so a Unified Command Post (UCP) must be established as soon as possible. But in the meantime, how might the LE on scene make use of the arriving fire fighters so that he or she can gain access to the building and engage the active-shooters? How will they render aid to the wounded and protect the firefighters? How will fire, LE and EMS coordinate to maximize responder safety while saving as many lives as possible? These are complex issues without clear-cut solutions.

Thankfully, the scenario described above, while similar to other events, is fictional. It describes a simulated experience developed as a means to better prepare first responders for AS/MCI events before they occur.

This paper documents the background of why such training is important, cross-organizational stakeholder goals, a description of how the exercise was conducted, outcomes, challenges and mitigation, and the way ahead for this effort.

2. BACKGROUND

In 2008, a terror attack in Mumbai, India (*Figure 1*) led to great loss of life, instability, and a series of lawsuits against the Indian government for failing to protect its people (Rand Corporation, 2009). This tragedy, in addition to a growing number of global terrorist events, exemplifies an increase in threat events (FBI Law Enforcement Bulletin, 2014) with the potential for increased complexity (Rand Corporation, 2009). DHS S&T FRG reached out to experts from the First Responder Resource Group (FRRG). The FRRG is a volunteer organization of individuals drawn from LE, Fire, EMS and emergency management across the United States. They identify capability gaps, set priorities and requirements and evaluate the newest responder tools (First Net, 2014). In 2011, the FRRG determined a virtual training capability was a high-priority cross-cutting training gap for response to attacks on the civilian population (DHS S&T FRG, 2013).

Figure 1 The Taj Mahal Hotel during the attack in Mumbai (Siddique, 2012)

Historically, training for ASEs has focused on small groups and individual disciplines, i.e. LE trains on a strictly LE response, etc. Though live training is optimal, cost and complexity prevent full-scale live training events from occurring frequently, with only a fraction of responders receiving training when they do occur. However, virtual training cannot replace the interactions involved in live training, but there are opportunities to significantly reduce costs while increasing responder proficiency. Virtual training simulations allow a large number of responders to train repeatedly, both as individuals and in teams. This potentially increases the depth and breadth of trainee involvement since exercises can be repeated at a fraction of the cost of a live event and can be used to prepare trainees to make better use of live training time. More importantly virtual training provides an increased opportunity for cross-discipline training.

Both the FRRG and DHS S&T FRG look across the modeling and simulation community in the hopes of leveraging previous work to reduce cost without sacrificing performance. This led to a partnership with the Army Research Laboratory-Human Research and Engineering Directorate, Simulation and Training Technology Center (ARL-HRED STTC). The ARL-HRED STTC has demonstrated extensive experience making use of commercial technology to improve preparedness. Individuals from the commercial modeling and simulation industry, academia, ARL-HRED STTC, DHS S&T FRG, along with first responders from Sacramento's Fire (including paramedics), LE, dispatch and Incident Command came together to establish the detailed requirements. The result was a virtual training prototype which was used to conduct a demonstration and training exercise in Sacramento in Fiscal Year 2014.

3. STAKEHOLDER GOALS

The primary stakeholders for this effort included DHS S&T FRG along with the FRRG, ARL-HRED STTC and Sacramento City Fire and Police Departments. Each had their own purpose and goals that led to their involvement in the effort. Support in the development of this capability was provided by both academia - University of Central Florida, Institute for Simulation and Training (UCF, IST) and industry.

3.1. DHS S&T FRG and FRRG Goals

DHS S&T FRG and the FRRG have seen a considerable increase in the number of active-shooter, and complex coordinated attacks on civilian targets world-wide. The group established training gaps to confront this issue. Specifics on the goals and desired capabilities follow.

The training framework needs to allow training at the tribal, local, state or federal level, allowing varying authorities, and policies. The goal was to provide a capability that would better prepare first responders from Walla Walla, Washington to New York, New York.

The objective is to develop readily-accessible, high-fidelity simulation tools to support training and exercise in incident response and management. This allows large numbers of responders to train repeatedly, both as individuals and in teams, in a classroom or distributed. Responders from multiple agencies, disciplines, and jurisdictions would be able to train for a coordinated incident response and have the flexibility to integrate their own location's operational tactics and procedures. The tool would need to be intentionally agnostic regarding tactics, allowing for local responders to determine their own tactics and strategies.

The base capability allows for future growth and scalable numbers of participants. The architecture needs to allow for additional locations to be modeled as well as additional functionality as needed. As commercial technology advances the architecture will be expanded upon to maximize the government's investment. Using commercial game technology was expected to improve participant engagement (Dwyer, Griffith, & Maxwell, 2011).

The training solution must allow for varying levels of complexity. The virtual simulation would support training from individual tasks at a single site for individual mastery all the way through situation mitigation through synchronized (not just coordinated) efforts of all groups at once.

Communication would have to be realistic with local proximity noise and voice communication as well as radio communication across various tactical channels. During a real attack, LE and Fire have multiple channels at their disposal while dispatch has the ability to link and unlink channels across LE and Fire as necessary. The virtual environment needs to allow for the same functionality.

Separate individual roles must allow different capabilities. For example, dispatch needs to have the tools available that they would at their traditional station. Incident Command would need to be able to share information via a white-board at the command post alongside other jurisdictions or agencies. Protective gear such as Self-Contained Breathing Apparatus (SCBA) and protective clothing would be used in the environment by fire fighters to improve survivability from smoke and heat (*figure 2-green dots show air supply in SCBA gear)*. LE would have a realistic ammunition supply.

Trainers would need to be able to capitalize on teachable moments by being able to observe or coach individuals during and after the exercise. An After Action Report (AAR) would be needed to review tactics, techniques and procedures or standard operating procedures.

It would be important to avoid dependency on high-cost hardware. Due to the environment being immersive and graphically rich, a graphics card is necessary; however, quite often computers used for training can be dated by five years or more, so the environment must be compatible with older hardware.

Finally, the intent was not to develop a handful of scenarios, but to allow for a multitude of scenarios. This led to a "sandbox" approach meaning that the virtual environment could support any variation of possibilities from an individual shooter to multiple intelligent shooters with incendiary devices. Actions in the environment would be managed through exercise control managing the actions of humans role-playing the attackers (Department of Homeland Security Science and Technology, 2014).

3.2. ARL-HRED STTC Goals

To meet these needs DHS S&T FRG partnered with the ARL-HRED STTC to share resources and reduce funding challenges. ARL HRED STTC had been exploring the use of commercial game technology to train specific Army skills (Dwyer, Griffith, & Maxwell, 2011). Their goal was to develop functionality that could be leveraged across the US government to reduce development costs while making the end-product free for Government end-users.

One of the greater costs of training can be making the time for the students to attend a training event. Sometimes the instructor is brought to the students to reduce costs. One goal for the Army is to make training available at the point of need. Students do not need to be co-located with the instructor. The technology must allow for local or distributed exercises. The environment should be available 24 hours a day, seven days a week.

The way many individuals train can vary depending on the situation as well as the user interfaces, especially as technology advances. It was important to allow for flexible user interface strategies. The use of simulated weapons, game controllers, floor pads, head-mounted displays, and wearable technology must all be able to interface into the environment.

Interoperability with traditional simulations is important to the ARL-HRED STTC so that multiple echelons can train simultaneously. Middleware is used to pass position location and interaction data, while a terrain generation pipeline ensures that terrain is correlated.

Both DHS S&T FRG and ARL-HRED STTC felt a graphically-rich, high fidelity environment would make training more realistic and believable.

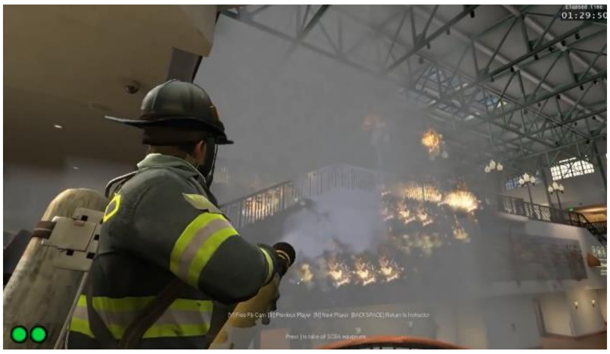

Figure 2: View from within the virtual environment (Nov 2013)

3.2.1. Enhanced Dynamic Geo-social Environment (EDGE)

The DHS virtual training prototype is the U.S. Government-owned Enhanced Dynamic Geosocial Environment (EDGE), which makes use of the commercial Unreal 3 Game Engine (Epic Games, 2015). ARL-HRED STTC began work on EDGE as a means toward leveraging high-fidelity training capability across the U.S. Federal Government. By developing capability that is shared across all Federal Agencies, a great deal of training capability can be established with small incremental investments being spread across different funding sources.

Having government rights to the source code of commercial technology experts can develop specific functionality and make it available to other government developers at no additional cost. For example, tactical movement with a weapon is very similar across the Army and first responders. This capability doesn't need to be created new for each level within the environment. However, new functionality, such as the use of naturally propagating fire that has realistic damage effects on characters in the environment, can be developed once and reused by various agencies. The more people who use and develop the architecture, the greater it benefits the government overall.

3.3. Sacramento First Responders' Goals

Sacramento Fire and LE were eager to participate in the pilot exercise. They provided subject matter experts from dispatch, incident command, LE, fire and EMS throughout requirements definition and development cycle to set training conditions. It was important to bring all the responders together for requirements identification as each of their needs were significantly different, for example LE needed three-dimensional acoustic indications of where shots were coming from in order to move to stimulus while Fire needed access to a lock-box to gain access to all rooms and a fire alarm that reacted to smoke.

Realistic victims that react to gunfire and fire were needed in the environment. They were designed to be both playable characters, and artificial intelligent agents. The victims played by role players had to be able to provide information on the attackers and have indications of their health and the ability to be carried to casualty collection points for assessment if wounded.

In partnership with DHS S&T FRG, Sacramento first responders selected a popular hotel as the virtual environment, a 26-floor hotel near the state capital and the convention center. Every detail of the hotel is faithfully depicted in the virtual environment. Every room is modeled in every area, including employee-only rooms such as the kitchen, offices, and freight delivery areas. The actual location of exit signs, the lock-box, elevators and fire hydrants are accurately represented. Though the specificity would suggest training would be targeted to the location, this location could be generalized to any hotel around the world.

4. CONDUCTING THE EXERCISE

Putting on a large scale virtual training exercise takes coordination and cooperation from many different groups. The planning may be as detailed as a live training event; training goals and objectives have to be identified and the scenario needs to be tailored to that end with strict adherence by role players. While it is time consuming, the payoff and the number of individuals and roles that are able to train is significant.

4.1. Facility Layout

In preparation for the pilot event, a site survey was conducted of the training facility to determine where each participant group would sit during the exercise. In order to remain organized, each group of first responders were grouped by their specialization. This allowed for better communication and made it easier for any troubleshooting that was necessary. The opposing forces, or shooters, were located in a room across from exercise control and far from the responders. Another room was set up to support AARs and to conduct surveys after the event. Each participant room had training observers and technical support and radios were used to coordinate with technical support and exercise control.

4.2. Network and Hardware

Prior to the participants' arrival, the network was laid down, computers were set up, and each client was tested for connectivity and sound. There were ten LE officers, ten fire fighters (three engines, three trucks), a LE and a fire dispatcher, a medical manager, medic strike team and three medics in the environment. Unified command also contained a LE sergeant, a watch commander, a scribe, and two fire battalion chiefs. There were four suspects and two civilians and finally, there was an exercise control logon that could fly through the environment (invisibly) to watch what was taking place and step into various characters avatars to witness their actions. This brought the total number of participants to about 40 individuals. The exercise took place with no computational degradation or performance issues.

4.3. Preparation and Train-up

The entire participant group received a briefing on the intent of the pilot event and a description of how they would enter and navigate the virtual environment. The participants broke out into their designated groups and received a tutorial explaining how to use their specific capabilities within the environment. For example, representatives from the fire battalions learned how to connect to a hydrant and move a hose in the virtual environment. Everyone received a video describing their actions and a reminder card was provided at each station. Each individual participated in an in-game tutorial that allowed them to practice the tasks. After the tutorials, participants were invited to enter the environment and 'play.' They were encouraged to explore the hotel and practice using their weapons, tools and communications (*figure 3)*.

4.4. Scenario Management

A Master Scenario Event List (MSEL) was established to direct events within the scenario. Initially the MSEL had timed events, such as: Start time + 30 seconds, 2 assailants enter third story lobby and engage hotel patrons, start time + 35 seconds first calls go out to dispatch of active-shooters in the hotel. The group ran through one practice scenario to gain familiarization during which it became clear that the scenario would need to be event driven rather than time driven since every action after the shots were fired was a reaction that would be conducted in real-time. From that point on, exercise control managed only exercise start, the movements of the opposing forces and exercise end.

The first time the exercise ran, the opposing force was asked to reduce their in-game aggressiveness. This provided the participants an opportunity to gain confidence in using the training tool. As expected, the first AAR following the initial run through had a significant number of comments about the user interface, communication and overall familiarization issues. This provided an opportunity for the technical support team to respond to questions and ensure everyone was at about the same level of competence within the environment before ramping up the complexity of the threat. The first run through the exercise took about 45 minutes with the AAR taking about the same amount of time to complete each group.

The large environment including the 26 floors and having quite a few employee-only corridors and loading docks, allowed for a wide range of scenario possibilities. Active-shooters were able to use fire in higher floors to corral victims and cut off support from responders. The scenarios were able to take on a complexity that increased as those training learned from their mistakes.

Figure 3: Participants in the Pilot Exercise (Nov 2013)

5. OUTCOMES

The successful event proved that it was possible to host a cross-collaborative virtual training event that would provide the problem-solving skills that would be necessary to take on a complex coordinated attack (National Urban Security Technology Laboratory, 2014). The most significant outcome noted by exercise control was the exposure of policy gaps. For example, what is the protocol for a fire response to an occupied structure with an active-shooter? There were also more routine issues such as LE wanting to turn off the interior fire alarm so officers can hear better but fire responders' concern that turning off the alarm will allow the elevators to operate and may encourage occupants to try to evacuate via the elevators. These previously unknown conflicts were identified and resolved locally. Ultimately, when confronted with the dual threat of an active-shooter in an occupied building, the teams determined fire could enter the building with LE providing protection. They were then able to conduct analysis on how the change of tactics worked from within the environment.

A common challenge for Incident Command is to direct the response with imperfect knowledge of what is taking place in the hot zone. Lack of communication across first responder departments and organizations is a well-known and well-documented problem that continues to hamper a coordinated response. For technical and tactical reasons, command frequently has an imperfect understanding of the event on the ground and as a result, Incident Command may have a completely different idea of what is happening compared to the individuals on-scene; clearly this can lead to serious consequences. However, the AAR provided a great opportunity to see where communication breakdown or misinterpretation occurred and provided an opportunity to address the issues. By better understanding the issues they contending with, both groups were able to improve communication.

6. CHALLENGES AND MITIGATION

Experts in the area of ASE and AS/ACI events agree that first responders "jointly develop local protocols for responding to AS/MCIs and Fire/EMS and LE should plan and train together" (Federal Emergency Management Agency (FEMA) U.S. Fire Administration, 2013). Limitations to training across organizations can be associated with conflicting training schedules or with access to training sites and resources. By using virtual training technology, training can be conducted at the point of need. It is possible to prepare for an incident in New York's Times Square, even if you are in Sacramento, California. Using commercial game technology, an individual joins a team to accomplish a complex task. The team can be distributed anywhere around the world. Similar commercial game technology is applied to training exercises described in this paper.

Building a simulation that encourages first responders to train together while not being tied to any particular doctrine or standard operating procedure is critical. Consider one jurisdiction where the policy is that the first individual on the scene of an ASE must wait for backup before engaging shooters while another jurisdiction requires responders to move to stimulus immediately. The virtual environment must allow all possible response possibilities. In the case of the prototype used for this event, interactions are not scripted, and just like real-life - anything can happen. This means events in the environment can and will get very messy and complicated with miscommunication and chaos. The intent is mistakes or learning moments happen in the virtual environment rather than while actual lives are at stake.

Running an exercise as a training event is not the same as that of traditional course work. Sometimes, there is no "correct response." Sometimes, the correct response is purely defined by the outcome and can only be assessed retrospectively. Take for instance the decision by the Kenyan security forces to delay entering the Westgate Mall, while plainclothes civilian rescuers and plainclothes police rushed in to engage terrorist attackers (British Broadcasting Corporation (BBC), 2014). The decision by the impromptu group could have endangered existing response activity or it could have saved considerable lives. Retrospectively, given the lack of State response the civilian response was warranted.

In order for an exercise to become a learning event, it is critical that observers be present to make note of actions at every level. For example, if the LE observer sees activities that violate doctrine, they are displayed and discussed during an AAR. Each component of the response team should receive a review of their individual performance during the exercise, and the larger team receives feedback on how each of the components worked as a team. Strengths and opportunities for improvements are highlighted and discussed. This is also a good time to discuss if protocols should be re-examined. After the exercise has been thoroughly reviewed, participants have the opportunity to apply the learning by running another exercise with varied details and make improvements.

Training for mass casualty events is often focused on one or two components of the event to simplify and focus training. For example, LE may focus on finding an active-shooter to stop the threat. However, they may not train on the events that follow, such as clearing the area and preserving evidence or providing timely care for wounded. With a virtual environment every activity associated with the response to an ASE can be accomplished. Details such as the control of traffic or the placement of the Incident Command Post (ICP) – that can bring about success or failure in an ASE (Los Angeles World Airports, 2014) – can be modeled and optimized in the virtual environment.

7. WAY AHEAD

DHS S&T FRG and ARL-HRED STTC are continuing to develop and evolve the virtual training model into a more robust and more widely accessible training tool to first responders throughout the nation. The STTC is using EDGE in their Visualization Test Bed (VTB) to explore strategies to improve realism, such as including a human-driven puppeteer into the environment. Larger terrain, strategies to control command and control robots and real-time tutoring are also capabilities being explored by the VTB.

Currently DHS S&T FRG is making virtual training available to training locations such as the California Fire and Rescue Training Authority, the Federal Law Enforcement Training Center (FLETC) and academic organizations such as the City University of New York School of Professional Studies in order to provide training to a large audience of first responders. Although development resources are limited, ongoing efforts are underway at DHS S&T and STTC to continue to not only improve the iterations of the current EDGE virtual training tool but also to expand the number and type of environments. As an example, a complex middle school has been modeled to allow for first responders to better prepare to respond to and mitigate such attacks. This environment also allows school officials to prepare their response protocols to prevent or minimize casualties.

Finally, international partners are receiving the benefit of the virtual training environment with the sharing of the EDGE virtual training tool to one 'pilot' country and discussions underway with others to follow.

8. CONCLUSION

Terrorism, unfortunately, is a part of our life for the foreseeable future. Asymmetric warfare or terrorism of the type favored by our current adversaries will continue to focus on nonmilitary civilian soft targets. It will benefit us all to prepare to the greatest extent possible to respond to AS/MCIs. Recent history has demonstrated the response to an AS/MCI must be pre-coordinated and preplanned with local agencies. An incident of this type will require a coordinated cross-discipline response and, currently, available training is inadequate to meet that need.

The training described in this paper (at no cost to responder agencies) by DHS and the U.S. Army is critical and will invariably save lives of not only responders, but also innocent civilians.

It is vital that responders have the opportunity to practice their ability to coordinate response tactics and strategy in a cross-discipline approach prior to responding to such an event in the real world. Virtual training provides the ability to prepare military troops as well as first responders in a realistic and cost effective manner.

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TOWARDS AN IMMERSIVE VIRTUAL REALITY TRAINING SYSTEM FOR CBRN DISASTER PREPAREDNESS

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ABSTRACT

Over the past decade, training in virtual reality for military and disaster preparedness has been increasingly recognized as an important adjunct to traditional modalities of real-life drills. However, there are only a few existing solutions that provide immersive virtual reality training that implies improved learning through an increased amount of presence. In this paper, we present a thorough analysis of the state of the art of virtual reality training systems and outline the requirements of two peer stakeholders for disaster relief with an explicit focus on CBRN disaster preparedness. We compare both analyses to specify if - and to which extent - existing virtual reality training solutions meet the stakeholder requirements. Based on the comparison, we present an outlook on existing and upcoming virtual reality components that have the potential to fulfil the stakeholders' requirements of a flexible multi-user immersive virtual reality training system.

Keywords: Virtual and Augmented Reality, First Responder, CBRN Disaster Preparedness, Scenario and Decision Simulation

1. INTRODUCTION & MOTIVATION

Effective training is a cornerstone of disaster preparedness. Quality, consistency and frequency of training are shown to impact self-perceived disaster readiness of first responder units. However, barriers such as time, cost and safety limit the extent to which large groups of responders can be brought up to established standards, particularly related to integrated disaster team response skills and experience. This is particularly evident during events involving large-scale mobilization of population-based healthcare and public health resources where skills learned through training impact directly the actual response. The advent of technologically-based approaches through Virtual Reality (VR) environments holds significant promise in its ability to bridge the gaps of other established training formats.

The training of professionals to face emergencies requires the mastery of several skills and abilities that need practice. However, facing real emergencies should be avoided during the initial stages of training. Instead, training should be provided under guidance and in a controlled setting that mimic real-life situations as closely as possible. VR integrates real-time computer graphics, body-tracking devices, visual displays and other sensory inputs to immerse individuals in computer-generated virtual environments. VR creates an illusion in the user of being physically inside the virtual world, and this sense of presence can have positive effects on task performance, enabling the learning situation to be experienced as a real context, which in turn promotes experiential learning. Indeed, VR enables individuals to learn by doing, through first-person experiences. Virtual Reality provides a tool for developing instruction along constructivist lines and an environment in which learners can actively pursue their knowledge needs. Another important characteristic to highlight is the possibility of self-learning and over-learning provided by these tools, since trainees can repeat the situation as many times as they want. Such activity is in part guided by the trainee, which promotes the development of operational and formal thinking by facilitating the exploration of different possibilities. This kind of training method can be readily adapted to the trainee's pace, timetable and needs. In addition, these tools enable the difficulty of the problems to be solved to be graded, thus facilitating learning by bringing subjects progressively closer to the solution.

Over the past decade, VR-based training in disaster preparedness has been increasingly recognized as an important adjunct to traditional modalities of real-life drills. Multiple studies, i.e. (Freeman et al. 2001; Wilkerson et al. 2008; Vincent et al. 2008; Farra et al. 2013) have highlighted VR applications in disaster training. Many government agencies have adopted until now VR-based training. However, existing solutions mostly offer desktop-based VR training that lacks visual 3D immersion and navigation by natural walking. Both factors decline the sense of presence. Furthermore, natural walking is essential to simulate stress and physical excitement, which is of particular interest to create a realistic training for on-site squad leaders and rescue teams. There are only a few existing solutions that provide immersive VR training through stereoscopic 3D scene viewing and body motion analysis (IntelligentDecisions 2015; Motion-Reality 2015). However, these systems are solely designed for military training, they are very expensive (more than $100.000) and require extensive technical knowledge for system setup. These factors heavily diminish their applicability for disaster training of first responder agencies since they require a flexible immersive VR system to enable multi-user, interdisciplinary team training at different command levels in various training scenarios.

As the first step towards such as flexible VR training system, we performed a thorough analysis of the state of the art of existing VR training systems. Furthermore, we analyzed the requirements of two peer stakeholders with a focus on chemical, biological, radiological and nuclear (CBRN) disaster preparedness. Subsequently, we compared both analyses to be able to formulate necessary future steps to develop a VR system meeting the essential stakeholder requirements. To summarized, the paper presents the following two contributions:

1. A comprehensive state of the art analysis that outlines the capabilities of existing VR systems for multi-user training.
2. A requirement analysis of two peer stakeholder - the Austrian Federal Ministry of Defense and Sports (BMLVS) and the Red Cross Innsbruck, Austria - with a focus on CBRN training tasks. Three uses cases are developed that describe training scenarios that would be highly beneficial to be trained with a VR system.

2. STATE OF THE ART ANALYSIS

Employing VR technology to train first responders and relief units is an ongoing research topic for about one decade (Stansfield et al. 1999) and has led to the development of several academic, military and commercially available systems. The aim of the following state of the art analysis is to describe internationally available VR training systems, either providing training for military, first responders or civil purposes. To be able to evaluate the applicability of existing systems for providing interdisciplinary training of disaster relief units, we focus on analyzing virtual reality systems that are capable of multi-user training.

Thus, we did not study systems that only provide single user training, systems to train negotiation & language skills (i.e. *Bilateral Negotiation Trainer - BiLAT*), or systems that enhance live exercises in outdoor environment (i.e. *Augmented Reality Software* by ARA - Applied Research Associates). Furthermore, we did not study in detail systems that solely exist as prototypes. However, as some of them show significant potential for future disaster preparedness training, we briefly summarize interesting projects. *Immersive Video Intelligence Network (IVIN)* (Ivin3D 2011) is a tool offering 360° building walkthroughs that are visualized on a mobile device's display. The building's' interior is produced from photos and is supposed to enhance the indoor situational awareness of first responder units. It does not provide an immersive setup, natural walking for navigation nor training functionality. *Sportevac* (University-Of-Southern-Mississippi 2015) is a desktop-based virtual training scenario simulating the challenges of a stadium evacuation with thousands of avatars, and the *Virtual Terrorism Response Academy* (Dartmouth-College 2015) is a desktop-based and non-immersive VR environment that aids trainees practicing various terrorism threats such as chemical hazards. The system *Enhanced Dynamic Geo-Social Environment (EDGE)* (U.S.-Army 2015a) is a VR platform with the major goal of enhancing first responders' communications and coordination while also making training more efficient and cost-effective. EDGE provides the creation of a dynamic, scalable and customizable training environment and supports multi-user training in a desktop-based, non-immersive virtual environment using a high-quality game engine for rendering, a standard screen for visualization and keyboard and mouse for navigation.

In the following, we outline the results of our state of the art analysis of available multi-user VR training systems. We categorized the systems into applications that either 1) provide pre-defined scenario(s) to train multiple users, or 2) allow the creation of various, self-defined scenarios that can be subsequently used for multi-user training. For pre-defined scenario systems, we provide an overview as they demonstrate well the potential of VR training. However, we will not go into all details of each approach as the pre-defined scenario systems lack out-of-the-box functionalities to create self-defined training scenarios with arbitrary devices, i.e. by providing open and accessible hard- and software interfaces. Thus, we describe in detail multi-scenario training systems as they might act as technological base to create immersive multi-user VR training systems for disaster preparedness.

2.1. Single Scenario Training for Multiple Users

A large number of simulators using VR technology exists to train military personnel for specific air, land and naval operations. Especially training of aircraft personnel has a long history, resulting in more than 1600 military aircraft simulators up to date that are in service worldwide (Farfard 2013). The most compelling simulation is provided by Full Flight Simulators (FFS), such as the *Navy MH-60 Romeo* or the *Eurofighter Aircrew Synthetic Training Aids (ASTA)* that comprises a Full Mission Simulator (FMS) and a Cockpit Trainer/Interactive Pilot Station – Enhanced (CT/IPS-E). In addition to simulators for aircraft on-board training, a number a simulators exists to train Unmanned Aircraft Systems (UASs), i.e. the *Predator Mission Aircrew Training System* (PMATS) or the *MQ-8 Fire Scout Unmanned Helicopter*. Since these systems are not of our primary interest for disaster preparedness training, we do not present more details.

For military operations at land, VR simulators exists to train gun handling, shooting as well as tank operations. The *Simulated Weapon Environment Testbed (SWeET)* (U.S.-Army 2015b) targets at small arm weapon design and testing. It uses five 2D screens to project a 300° view of indoor or outdoor scenarios with customized weather conditions, locations and times of day. At each screen, up to four users can perform the exercise. The *Small Arms Trainer with 180 Degree Visuals (180SAT)* (Ameldefense 2015) aims at training of marksmanship skills, situational awareness and reaction times to increase the effectiveness of trainee usage of weapons in realistic threat scenarios. The system comprises large 2D projection walls and screens that are configured for individual and two-person team training. To train handling and operation of tanks, various systems exists, i.e. the *Leopard Gunnery Skills Trainers (LGST)* (Rheinmetall-Defense 2015b). It is a self-contained, standalone system to train Leopard 2A4 crew commanders, gunners and loaders. Therefore, it provides at least six desktop-based workstations and one Driver Station Simulator (DSS) to enable multi-user tactical training at platoon level. The DSS simulates the tank interior with actual hardware and allows the driver to take part in the tactical training. Each workstation is equipped with multiple 2D screens, headset and microphone for communication as well as mouse and keyboard for interaction.

Besides training in the aforementioned environments, also systems for exercising naval operations exist, i.e. the *Visual Bridge Simulator* (Marin 2015) that is used to train all warfare branch officers, except aircrew, for the entire range of watch keeping, ship-handling and navigation at different command levels. Another example is the VR Team Trainer (Szenaris 2015) (also named *Cooperative Computer Based Training* by the German Armed Forces) that aims at exercising control, operation and usage of complex systems such as M3 amphibious vehicles. Therefore, the trainees' task is to couple together amphibious vehicles, boats and floating bridge elements in a waterway to form ferries or bridges. Before simulation start, the trainer can configure scenario parameters such as current speed, visibility and wind velocity. The hardware setup comprises a desktop-based VR system, consisting of three to four user workstations, a gesture recognition workstation, a trainer workstation, a shared view workstation and a vehicle simulator. The user workstations are equipped with 2D screens, headset, microphone, keyboard and joystick, the gesture recognition workstation provides a keyboard and a data glove to capture hand gestures. The vehicle simulator offers a 360° projection combined with force feedback for realistic vehicle simulation.

The presented systems cover a wide range of training scenarios and outline the application of VR systems for real-world training tasks at different command levels. However, they share the limitation not providing out of the box accessible hard- and software interfaces to extend the systems for disaster preparedness training.

2.2. Multiple Scenario Training for Multiple Users

To create multiple scenarios for training of multiple users, there has been active development by industry, both offering VR training systems for military as well as civil usage. The amount of immersion provided by the VR training systems range from non-immersive desktop-based to fully immersive environments.

2.2.1. Non-Immersive VR Systems

The software framework *Virtual Battle Space 3* (Bohemia-Interactive 2015) offers training of unit tactics, techniques and procedures in decisive actions for soldiers. Its open software platform enables 3rd party products to extend the simulation environment and functionality. To create self-defined training scenarios, it offers several built-in applications, including mission editors, an after-action review module, a development suite, a 3D content creation module including a model library and a modeling tool. The mission editor module comprises an offline editor to create scenarios at air, land and sea, to prepare terrain, objects, avatars, vehicles, weather (i.e. weather, sun, and time of day). The real-time mission editor enables the trainer to influence the scenario during training. With the help of the after action review module, post-training analysis can be conducted with the ability to visually fast-forward or rewind to events. Amongst others, it tracks statistics on casualties, engagement time and rounds fired and provides trainers and trainees to view the scenario from different perspectives including 3D, 2D, and from any trainee's perspective. The real-time 3D simulation is based on the game engine *Real Virtuality 3* combined with *nvidia PhysX*. The network module is optimized for a large number of trainees (> 100) and enables to interconnect several Virtual Battle Space servers together or connect with other military simulations.

Figure 1: Multi-user training with Virtual Battle Space (Bohemia-Interactive 2015)

Out of the box, Virtual Battle Space supports standard workstations for each user with 2D monitors, keyboard and mouse as well as headset and microphone, resulting in a non-immersive desktop-based VR setup (see Figure 1). It is used by a number of armed forces worldwide, including the U.S. Army, U.S. Marine Corps, UK Ministry of Defense, German Armed Forces and NATO. Due to the open software framework, it is furthermore used as base technology for a number of training tools, i.e. *Unmanned Aircraft System Training (UAS-TS)* for tactic drone LUNA (eurosimtec GmbH for German Armed Forces) and the *Leopard Gunnery Skills Trainers*.

The system *XVR - Virtual Reality Training Software for Safety and Security* (E-semble 2015) aims at training and exercising of emergency response professionals. It offers education, training and assessment of incident commanders of operational level up to strategic level, i.e. for members of relief units from emergency services, industry and critical infrastructure. By default, it offers single or multi-user training in a networked environment based on standard computer hardware, using a workstation, 2D screen, keyboard, mouse and joystick. Its software framework offers an editor for rich 3D content creation. The editor allows the configuration of region, incident or disaster scene as well as the determination of indecent type, scale and location. Further incident parameters – i.e. number of rescue vehicles, personal on call – can be customized, forcing the trainees to take into account logistic aspects such as call-up and transport times. During simulation, the trainee uses the joystick to navigate around the environment (walk, drive, fly) to assess risks and dangers of an incident. The trainer can give live feedback and can respond to a trainee's decision by activating events in the virtual scenario. XVR provides the creation of specific assessment scenarios to create predictable and repeatable training environments for an unbiased assessment. The system is used by a number of companies, organizations and state agencies, including ExxonMobil/Netherlands, BASF/Germany, Mont Blanc Tunnel/France&Italy, London Fire Brigade/UK and Austrian State Fire Brigade School.

The *Advanced Disaster Management Simulator (ADMS)* (ETC-Simulation 2015) offers training for incident command and disaster management teams at all command levels. It provides a large number of modeled 3D environments to train in scenarios that simulate building collapses, plane crashes, crowd riots, or nuclear, biological and chemical hazards. One example of the 3D simulation is given in Figure 2. The built-in scenario editor allows the configuration of generic, semi-specific or specific 3D environments, incident sites (type, scale and location) and incident specific parameters such as vehicle positions, time of day, precipitation, wind, visibility, condition of casualties, terrain, and traffic as well as bystander behavior.

Figure 2: Decontamination simulation with ADMS (ETC-Simulation 2015)

For performance evaluation, ADMS provides an observation and scoring system and an after action reviewer that records the exercise. In playback mode, training staffers can start, stop, pause and fast-forward the exercise and look at the incident from any point of view. ADMS comes as a modular, expandable disaster simulation platform using proprietary hardware and software (operating system). Thus, specific workstations are required and must be individually purchased. For visualization, projection walls or standard screens are used while interaction is performed with several physical input devices, such as keyboard, joystick or driving wheel. Amongst others, the system is used by the New York City Office of Emergency Management and Netherlands Institute for Safety (NIFV).

2.2.2. Semi to Full Immersive VR Systems

Compared to the systems presented in Section 2.2.1, we will outline in the following systems that provides training in semi to fully immersive virtual environments. The *Advanced Network Trainer (ANTares)* (Rheinmetall-Defense 2015a), a system developed for the German Armed Forces, is a land, air, naval weapon system simulator for tactical training operations. Its system's most prominent feature is the modular cubicle hardware concept. It allows to couple multiple, individually equipped simulation cubes to create a networked environment for tactical mission rehearsal of complex operations or scenarios. The open architecture provides the integration of different systems to form a complex networked mission scenario. The cubes can be arranged as plug-and- play components in a customer-defined configuration. The hardware for visualization and interaction of each cube can be individually customized, ranging from off the shelf visualization and interaction devices (i.e. 2D screens, head mounted displays (HMD), keyboard, mouse, joystick, force feedback devices) to fully equipped maneuver stations with actual hardware. Internally, ANTares uses Virtual Battle Space (version 2.0) for 3D scenario creation, training simulation and debriefing.

The immersive VR system *Dismounted Soldier Training System (DSTS)* (IntelligentDecisions 2015) offers training of dismounted soldiers of infantry platoons. One DSTS hardware suite comprises nine fully wearable and immersive VR setups (Virtual Soldier Manned Module - VSMM) for dismounted soldier training, five workstations for multifunction soldier training, one staff control station and an after action review space. The DSTS suite is depicted in Figure 3. Each VSMM consists of a helmet with attached HMD, headset, microphone and an *Intersense InertiaCube 2+* for 3D orientation estimation of the head. For processing, rendering and networking, a notebook is attached to the soldier's vest that also accommodates another *InertiaCube 2+* for torso tracking. Additionally, a gun is provided, equipped with buttons for navigation and an *Intersense InertiaCube 3* for 3D orientation tracking of the weapon. The VSMM allows each dismounted soldier to stand, crouch, jump and lay during the exercise. Movement and thus navigation is done by button controls at the weapon.

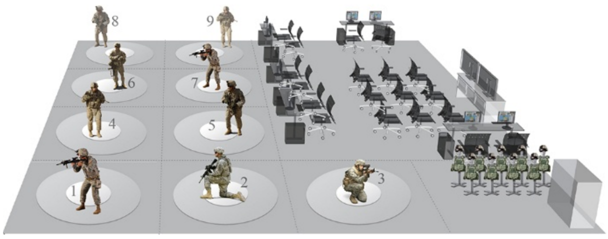

Figure 3:Setup of one DSTS suit (IntelligentDecisions 2015)

At the software side, a content editor allows the creation of self-defined training scenarios incorporating semi-automated forces and the live participants. Scenario related parameters, such as movement of ground vehicles, aircraft, dismounted infantry, day time and weather effects can be configured. Built upon the commercially available *CryEngine* (Crytek 2015), the systems offers high quality 3D rendering with physics support. The system was developed by Intelligent Decisions for the U.S. Army and is available since 2012. According to the U.S. army, 102 test sites were planned in 2012 to be equipped with DSTS, costing $500.000 for one suite. In 2014, Intelligent Decisions, announced the system *Medical Simulation* (The-Verge 2015), a training environment for first responders. According to the provided specifications, the hardware setup is similar to DSTS, extended by biosensors to track gaze, blood pressure and heart rate. However, no information are giving regarding system availability or costs.

VirtSim (Motion-Reality 2015) offers multi-user, fully immersive training for law enforcement situations as well as military tactic training at a squad command level. Therefore, it employs optical outside-in tracking (*Vicon*) to estimate the position and orientation of user's head, weapon and full body motion, as shown in Figure 4. This allows users to navigate in VR by real walking in larger sized physical spaces (20x20m). However, a plethora of Vicon tracking cameras is required to cover that volume (see the red lights in Figure 4), making the system hard to setup and highly expensive. Off the shelf HMDs are used for stereoscopic 3D scene viewing that are connected to a user-carried notebook that performs processing, rendering and networking.

Figure 4:Natural walking in immersive VR with VirtSim (Motion-Reality 2015)

The *VirtSim* content editor provides a range of reconfigurable environments. For law enforcement, pre-defined scenarios exists for training of individuals in weapon discipline, making deadly force decisions, covering danger areas, team clearing techniques, use of cover and concealment, and communications among team members. Military scenarios comprises training of individuals in direct action, counter-terrorism and react to contact. An after action review module records trainees' body motions, shots, the individual maneuvers of participants as well as team and squad maneuvers. It provides playback of all actions and shots from every angle, and from each participant's perspective.

3. REQUIREMENT ANALYSIS

A requirement analysis was conducted by two peer stakeholders for disaster relief, the *Austrian Federal Ministry of Defense and Sports (BMLVS)* and the *Ambulance Team of the Red Cross Innsbruck, Austria*. Within this analysis, the interests and requirements of both stakeholders' CBRN defense elements were firstly identified. Next, scenarios were developed and described to derive demands to a VR training system. Within the scenarios, the stakeholders furthermore focused on specifying the involved command levels, the target groups and the required training content.

To identify VR-relevant training parameters, the skill catalog for CBRN defense of the Austrian Armed Forces was used as base. Some selected skills are listed below for the subareas CBRN recce, decontamination, search and rescue, water purification as well as aircraft rescue and CBRN explosive ordnance disposal:

- CBRN collective protection
- Advisory services
- CBRN warning and alert
- CBRN observation
- CBRN exploration
- CBRN warfare agent examination
- Partly decontamination
- Full decontamination
- Finally decontamination
- Water testing
- Water purification
- Urban search and rescue
- Deflecting fire protection
- Aircraft rescue

All of the skills were subsequently analyzed with the following parameters:

- Training form
- Infrastructure
- Time resources
- Material resources
- Human resources
- Cost

In a second step, the identified skills were bundled (*skill bundles*) to find possible combinations for the purposes of dependencies with an influence matrix for the further analysis. So with the first step the relevant skills were identified and the second step was to reduce to some skill bundles. At least three skill bundles with a high potential to be trained in VR were identified:

1. CBRN-defense recce
2. Urban search and rescue
3. Skills for aircraft rescue

It has to be noted for skill bundle 3, that special CBRN defense platoons in duty exist on military airfields. Their main task is aircraft rescue after a crash while CBRN defense is an additional tasks with lower priority. Beyond the above mentioned skills for CBRN defense, the skills for decontamination and firefighting have been included into the analysis. The skills for CBRN collective protection, water purification as well as specific explosive ordnance disposal were identified as not relevant for VR training.

Based on the identified skill bundles, three use cases have been derived that are described in detail in the following subsections. All three uses cases outline training scenarios that would be highly beneficial to be trained with a VR system.

3.1. Scenario: *CBRN Defense Recce*

For this scenario, a virtual area of approximately 30x30km with a 24km airspace is required for the training of motorized and stationary elements.

The virtual environment should comprise a rural area containing some villages and infrastructure like bridges, power lines, railways or streets. This scenario aims at training of a CBRN defense recce platoon consisting of three specific vehicles and 28 staff members in different functions, such as platoon leader, squad leader, signal, driver, etc. Thus, at least 28 persons are directly involved in the virtual environment, requiring a multi-user collaborative VR system. The major mission tasks are:

- Observing
- Detection
- Decontamination

For the virtual simulation, it is necessary to customize the simulated hazard materials – i.e. chemical agents or radiological materials in various physical states – the weather conditions and time of day. Furthermore, it is required to move within the map, either within the entire map by controlling the virtual vehicles or by natural walking within a smaller physical volume (20x20m) for dismounted CBRN operations, as shown in Figure 5.

Figure 5: Armored CBRN recce vehicle and dismounted soldiers

Furthermore, the virtual buildings can be entered and it is possible to communicate with the virtual bystanders in the simulated environment. For dismounted operations, the CBRN squad staff must be able to wear their actual defense protection suites, some additional equipment and radio sets. Amongst other, there are the following benefits employing a VR simulation to train this scenario:

- The scenario can be used for team, group and platoon training/education as well as for single user training/education.
- The process of decision making can be trained as often as required for leaders of all levels.
- It is possible to visualize different areas, seasons and precipitation upon request. Furthermore, necessary tools and instruments can be virtually simulated.

In a real-world environment, providing all of the required infrastructure, participants and equipment for the intended training scenario is a cost and time extensive process, especially since there is a large amount of resources necessary. Furthermore, only a very small amount of hazardous material can be used for training since environmental contamination has to be avoided. Thus, using VR implies a tremendous potential to save costs and time, train the full range of hazardous material and provide training on a regular schedule.

3.2. Scenario: *Search and Rescue*

For this scenario, the virtual environment consists of an urban area, containing at least four to five buildings. Each two to four-storey high building has a cellar and shows different damages caused by an earthquake. Examples are given in Figure 6. It shows a typical earthquake scenario with totally damaged buildings as well as medium and light damaged ones.

Figure 6: Austrian Forces Disaster Relief Unit (AFDRU) on an earthquake site, Turkey

This scenario is targeted for training of the search and rescue elements of a search and rescue platoon. At least 45 soldiers are involved in the simulation at different command levels. So members of each command level have to cover specific topics to collaboratively solve the major mission tasks:

- Exploration
- Searching
- Rescue of persons
- Clearing

For scenario creation, building structures (door entries, properties of staircases), obstacles and affected persons (amount, various injury patterns) should be straightforwardly to generate and customized. Furthermore, parameters such as weather and time of day should be adaptable. Compared to training in a real environment, there are the following benefits employing a VR simulation to train this scenario:

- Training and education of decision makers of all levels of a search and rescue platoon can be performed with this simulated scenario.
- It is possible to simulate medium earthquakes as well as large damages of the building structures.
- Various hazards can be simulated as well as number of casualties and the grade of injuries.

Upon decision making of a specific thread are rescue operations, a lot of different equipment is subsequently required and used on site such as generators, devices for drilling, crushing and cutting. However, we found no benefit to incorporate the training of their handling into the VR simulation due the following reasons. Firstly, a lot of quick to provide real-world training of these tools exist. Secondly, haptic and tactile clues as well as force feedback are important to train their correct handling. At the current state of the art of VR input technology, it is very hard or still impossible to mimic these tactile sensations in a realistic manner. Thus, we excluded equipment handling from this VR training scenario. To summarize, this scenario aims specifically at decision makers of all command levels and does not target (dismounted) personnel of a squad unit.

3.3. Scenario: *Aircraft Rescue and CBRN Defense*

This scenario aims at training of some specific CBRN-defense elements on military airfields. In case of an airplane crash, their priority is to rescue the pilots. This implies specific requirements to which these rescue units have to obey, such as arriving on the disaster site within 90 seconds and start firefighting within 2 minutes after the crash. Furthermore, the relief unit staff have to know all relevant parameters and specific handles of all aircraft types that are currently in use in Austria. A large number of different on-site hazards are possible such as explosives of ammunition, fuel and safety devices like ejection seats. All the safety devices depending on the various types of aircrafts must be known and correctly handled in case of an emergency to avoid false releases. Thus, the soldiers must be extensively trained to know by heart all necessary procedures. Therefore, drill training is often used.

This training scenario is not developed for decision making but for training of standardized procedures depending on the different airplane types. Thus, the virtual environment provides the trainees a training facility to improve their experience and handling on the basis of unlimited repetitions. Additionally, the virtual training scenario allows training in a virtual simulation of the different real airfields. Hence, trainees do not need to visit the various aircrafts in their real home bases, resulting in a reduction of time and costs.

3.4. Derivatives

In accordance to the developed scenarios there are some general and specific derivatives identified. The general derivatives were categorized as:

- Movement (virtual and physical)
- Manipulation of Virtual Objects
- Communication
- Customization of Scenario Content & Parameters

The specific derivatives were categorized as:

- Specific Movements
- Specific Manipulations

For the scenario *CBRN Defense Recce* some of the necessary activities are listed below:

- Operate CBRN observation post
- Develop a weather report
- CBRN exploration

For each activity of all three scenarios the derivatives were identified. One example is given in Figure 7 in which the identified derivatives for the activity "Operate CBRN observation post" are outlined.

communication	team communication (speech, signs)
	team communication (radio)
	communication to commander via radio
	instruction to virtual person
manipulation	Transportation of equipment
	transportation of weapons
	map consulting
specific manipulation	**reading measurement results**
movement	going
	running
	sitting in vehicle
	lay on the ground
	bend down, lay down
specific movement	**dismount**
Customization of Scenario Content & Parameters	virtual persons
	hazard - chemical agent
	hazard - nuclear explosion

Figure 7: Derivatives for activity "Operate CBRN observation post"

To specify these derivatives, it was necessary to identify and describe the generic processes of each of the three scenarios. For instance, the search and rescue scenario consists of seven generic steps and the CBRN Defense recce scenario consists of seven activities. For each of activity the content was formulated and analyzed with regard to its applicability in a VR training application.

4. TOWARDS AN IMMERSIVE VR SETUP

Based on the analysis of the stakeholders' requirements, the demands on a VR training systems can be derived and summarized as follows.

4.1. Virtual Reality Objectives

The training environment should be 1) fully immersive to exploit the advantages of learning in VR, 2) it should provide 3D object interaction (selection and manipulation), 3) natural walking for navigation and to realistically simulate stress and exhaustion, and 4) it and should be multi-user capable to allow for collaborative training.

4.2. Hardware Objectives

The immersive VR hardware setup should be 1) fully wearable, 2) quick to setup, 3) consists strictly of off the shelf hardware components and 4) requires a small amount of hardware to lower price and system complexity.

4.3. Software Objectives

The software framework should provide 1) creation of new 3D training scenarios, 2) level and terrain editor, 3) customization of scenario parameters before and during the training, 3) high quality 3D rendering with physics support and 4) after action reviewing for trainee evaluation.

4.4. Discussion & Conclusion

The summarized peer stakeholder requirements are not met entirely by any existing system. While DSTS offers fully immersed multi-user training, it does not provide natural walking and 3D object interaction. VirtSim offers full immersion combined with real walking, but does not provide the unbound creation of new training scenarios. Furthermore, both DSTS and VirtSim are too expensive for many disaster relief units to be implemented as an everyday training system. The software framework of both Virtual Battle Space and XVR are promising, as they provide rich 3D scenario generation, parameter customization, high quality rendering and an after action review module. Both work with standard hardware, making the system capable to be extended with off the shelf VR hardware. This is particular true for Virtual Battle Space as it provides an open platform architecture. Although the Advanced Disaster Management Simulator offers a rich scenario editor for disaster training, its proprietary hardware making the system incapable for 3rd party extensions.

To conclude, a novel hard- and software VR system must be developed that should built-upon existing solutions. It is subject to future work to evaluate if either Virtual Battle Space or XVR should be employed as core software technology. Both need to be heavily extended to communicate with the required immersive VR hardware. The recently as free-to-use released game engine *Unreal* should be also considered at future developments, as provides high quality rendering and physics support. Commercially available and upcoming VR hardware, in particular *Samsung Gear VR* for fully immersive stereoscopic scene viewing, *Virtuix Omni* or *Cyberith Virtualizer* to provide natural walking, and *Microsoft Kinect* as structured light sensor for natural 3D object interaction have the potential to form the hardware base that meet the outlined stakeholder requirements.

5. CONCLUSION

In this paper, we outlined the current state of the art in immersive VR training systems for military and civil usage and described the requirements of two peer stakeholders with a focus on CBRN disaster preparedness. Both analyses form the two main contributions of the paper. Subsequently, we evaluated the two analyses to specify if - and to which extent - existing solutions meet the stakeholder requirements.

We came to the conclusion that no available systems can satisfy all demands and that no existing solution focuses on CBRN preparedness training in immersive VR. Thus, we formulated an outlook on upcoming VR components that have the potential to fulfil the stakeholders’ requirements of a flexible, multi-user immersive VR training system.

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DIMENSIONS OF INSTRUCTIONAL MANAGEMENT RESEARCH IN SUPPORT OF A GENERALIZED INTELLIGENT FRAMEWORK FOR TUTORING (GIFT)

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ABSTRACT
Adaptive training solutions require pedagogically sound instructional management that efficiently moderates a learner's experience through content selection, guidance, and feedback. To efficiently moderate learning experiences in a self-regulated training environment a developer must account for multiple facets of the learning process that ultimately impact how people build knowledge and develop skill. In this paper we present dimensions of instructional management that influence dedicated research efforts in support of the Army Learning Model vision to increase the use of adaptive training solutions. We begin by presenting driving requirements associated with this research, followed by a background on the Generalized Intelligent Framework for Tutoring (GIFT) being developed to support this vision. We conclude with four instructional management end-state themes that motivate current and future research efforts, including: (1) guidance and scaffolding; (2) social dynamics and virtual humans; (3) metacognition and self-regulated learning; and (4) personalization and non-cognitive factors.

Keywords: instructional management, adaptive training, intelligent tutoring systems, pedagogy

1. INTRODUCTION
The instructional or pedagogical model in an Intelligent Tutoring System (ITS) is responsible for directing adaptive strategy implementations by acting on learner relevant data and linking strategy calls with context relevant tactics associated with the domain, and supported by the training environment. This involves a tutor agent interacting with the learner (e.g., feedback, questions, hints, pumps, and prompts), as well as the training environment (e.g., scenario adaptations and problem selection), through methods grounded in learning theory. To optimize pedagogical models in adaptive training environments, techniques must be established that define strategy types based on a learner's prior experience and their associated traits and states that affect how individuals create knowledge and develop skill. Techniques are based on prior research in the field and organized around empirical evaluations informing their application and effectiveness (Wang-Costello, Goldberg, Tarr, Cintron, and Jiang 2013, Goldberg, Brawner, Sottilare, Tarr, Billings, and Malone 2012, Person and Graesser 2003).
A barrier to the success of this research is scope. Instructional management as a whole is a large research space with a number of dimensions guiding its implementation. To manage this appropriately, it is important to organize overarching requirements to guide developmental efforts. This strategy lends itself to defining desired end-states that informs design and dictates model representations. In the sections to follow, we first review recognized Army requirements that are motivating this line of research and development; then we present current progress on an ARL program dedicated to the advancement of adaptive training in the military called the Generalized Intelligent Framework for Tutoring (GIFT). This is followed by a review of instructional management research dimensions that cover the breadth of capabilities an ideal system possesses to optimize learning experiences in a distributed environment in the absence of live instruction.

2. DRIVING ARMY REQUIREMENTS
The Army' Training and Doctrine Command (TRADOC) defines Warfighter Outcomes (WFOs) on a regular basis for the purpose of directing and influencing science and technology research within the department of defense. WFOs are used to articulate warfigther capability needs, with advancements in training practices being listed as a critical requirement. For the purposes of our research, four specific WFOs are influencing directed end-states. These include: adaptive training and education systems; big data; training at the point-of-need; and artificial intelligence. In the following sub-sections we give a brief overview of the WFOs of interest and how instructional management research will be applied to address recognized gaps.

2.1. Adaptive Training and Education Systems
This gap is based on the recognition that there is a lack of adaptive solutions to support individual and collective training across the Department of the Army.

What is needed is a capability to assist trainees in the absence of live instruction that adapts to their Knowledge, Skills, and Abilities (KSAs) for efficient knowledge and skill acquisition that transfers to the operational environment.

An effective adaptive training capability is dependent on sound instructional management practices. Instructional management practices are composed of techniques, strategies, and tactics applied to a domain of instruction so as to optimize performance outcomes (Sottilare, Graesser, Hu, and Goldberg 2014). With respect to GIFT, this vector of research is concerned with identifying instructional best practices that associate with all facets of learning, as well as establishing authoring workflows that instantiate those practices across multiple environments of instruction. The goal is to provide adaptive training solutions that are sufficiently adaptive for each individual Soldier and for teams of Soldiers.

2.2. Big Data

The Army recognizes the need for a capability to handle and process an abundance of data associated with training practices to better design and optimize programs of instruction. From a training effectiveness perspective, data is available to evaluate training techniques and strategies applied to observe their effect on training outcomes that associate with skill acquisition and the progression from novice to expert. With adaptive training solutions supporting distributed and collective events, tools and methods can be created to automate data analysis for the purpose of assessing all components of a training event and how their implementation characteristics influenced performance measures.

A goal of instructional management in GIFT is to optimize performance and competency outcomes through personalized training experiences that adapt to an individual's KSAs. A connection between Big Data and instructional management is applying large data sets from prior course interactions to update and improve technique and strategy implementations across all available courses. A challenge with defining instructional management logic in a domain-independent context is that it requires generalizability across applications. An issue with instructional strategy based research is that an approach taken in one domain is hard to translate to a different without performing extensive research to validate its application. In addition, it is difficult define definitive instructional management logic based on these uncertainties. As such, big data can be used to account for this uncertainty by applying machine learning and data mining techniques to assess specific causal relationships between instructional practices and outcomes on performance, retention, and transfer. This application of big data is used to reinforce instructional management models by optimizing itself over time as more and more data is made available.

2.3. Point of Need Training

This driving requirement is based on a recognition that the Army lacks cost-effective and easily accessible learning materials that support a model of training at convenience. To facilitate this perspective, advancements in distributed training practices must be researched to support web-based, cloud-driven delivery methods that allow a trainee to access materials from anywhere with an appropriate network connection.

A goal of instructional management in GIFT is to support a model of training by convenience and to have mechanisms to support this form of education in the absence of live instruction. Effective training applications administered in a point of need capacity requires four primary components to deliver sound instruction: (1) the ability to monitor trainee interaction and behavior to accurately assess performance against a granular concept by concept model, (2) the ability to communicate guidance and feedback messages that correspond with individual performance, (3) the ability to adapt scenario/problem elements to maintain appropriate challenge levels for promoting flow, and (4) the ability to manage an automated After-Action Review (AAR) to review scenario performance and promote reflection on the linkage between outcomes and overall learning objectives. Each of these components are dependent on each other for the purpose of delivering personalized training experiences through an easily distributed, web-based open-enterprise architecture.

In addition, an optimal adaptive training capability will leverage existing course materials to better serve the development of a competency through point of need functions. An example is providing a remedial training activity on an indentified weakness in-between training events to better prepare that individual for the next period of instruction (e.g., recognizing trigger squeeze problems in the EST and providing a remedial multimedia training event prior to the next round of marksmanship instruction on the live range).

2.4. Artificial Intelligence (AI) Capabilities

This driving requirement is based on a need for an automated capability to replicate interactions, complexities, and uncertainties associated with executing mission oriented tasks in an operational environment. AI in education and training associates with the adaptiveness of virtual humans embedded in a training experience, how an ITS manages pedagogical decisions, and how scenarios can adapt and respond to trainee inputs.

A goal of instructional management in GIFT is to facilitate robust AI capabilities that enhance the realism and playability of simulation-based training exercises; specifically those that utilize virtual humans and semi-automated forces. These elements must be embedded with AI capabilities that provide an automated reactive capacity to trainee inputs and actions that adhere to the complexity and uncertainty of an operational environment. In terms of Virtual Humans, these entities must have logic that supports realistic movements and communication exchanges that reflect back to a culture or operational environment. This requires AI embedded within Virtual Humans that accounts for cultural norms and customs, along with the ability for the entity to adapt its behavior based on cues and actions perceived from the trainee (e.g., rolling of the eyes, change in vocal intonation, failing to account for appropriate cultural greeting, etc.).

AI also needs to be embedded in Virtual Humans that enables their use as virtual teammates in a collaborative training scenario. This will allow for effective training of team-oriented missions without the requirement of utilizing an all human team. In terms of semi-automated forces, which are commonly used in tactical training events within environments such as VBS3, AI techniques must be established that allow a group of forces to adapt their movements overtime as it can autonomously learn from actions and tactics executed by a trainee or team of trainees. This will allow a set of enemy forces to better adapt itself, much like in the real world, for the purpose of creating richer training experiences that increase complexity. In addition, AI techniques must be investigated to ease the development of training scenarios to avoid issues of replay-ability. A system such as VBS3 would benefit from technologies that enable the generation of multiple scenarios for training purposes based solely around a defined set of tasks, conditions and standards. This promotes better training because a trainee needs to adapt their application of knowledge and skills to an unknown event, rather than gaming a scenario by learning the various cues and scripts executed by an enemy entity (i.e., knowing an insurgent is hiding behind a specific door in a specific hallway).

3. INSTRUCTIONAL MANAGEMENT FUNCTIONS CURRENTLY IN GIFT

Before we examine specific goals and research interests associated with instructional management in GIFT, it is important to review some high level components of the architecture. This involves an understanding of how information and data is represented, and how these representations ultimately inform the Adaptive Tutoring Learning Effect Chain (ATLEC; Sottilare, Ragusa, Hoffman, & Goldberg, 2013; see Figure 1). The important takeaway of the ATLEC is the flow of data with respect to the selection of an instructional practice. The effect chain is influenced by both historical data (e.g., prior experience, prior knowledge, learner traits, etc.) maintained over time and real-time data captured during a specific interaction. This data is used to adapt instruction on two facets: (1) an inner-loop capacity using data to influence interaction within a single problem or scenario by providing guidance or adjusting difficulty levels similarly to Vygotsky's (1987) Zone of Proximal Development; and (2) an outer-loop capacity that configures the next event experienced by a learner based on assessments from a prior event or through predictions based on historical representations and learner traits (VanLehn, 2006). This might involve selecting a new problem/scenario, managing a remediation event, moving on to a new section of the course, administering an AAR, or ending the course.

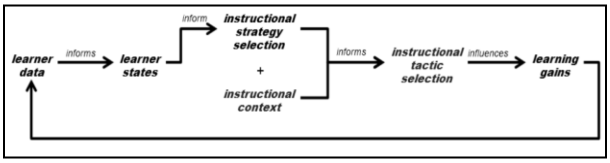

Figure 1: Adaptive Tutoring Learning Effect Chain

In terms of the inner-loop adaptive function, the ATLEC primarily interacts on learner assessments occurring in real-time for both performance and affective related states. Ultimately, raw interaction data is used to infer a learner state from. This involves robust assessment techniques that can accurately gauge an individual learner's performance for a given task, the affective responses they are having within that task, and their estimated competency for the domain that task is designed to train. This inferred learner state is used to inform the selection of an instructional strategy to mediate the learning experience. In the current baseline of GIFT (e.g., release GIFT2015-1 on https://www.gifttutoring.org), the instructional strategies supported for the inner-loop consists of "provide guidance", "adapt scenario", "administer assessment" and "do nothing". These strategies are represented as high-level domain independent descriptors of an action the system can take within a given learner event. These high level actions must then be translated into a specific tactic of execution (see Sottilare, Graesser, Hu & Goldberg, 2014 for a comprehensive breakdown of strategies vs. tactics).

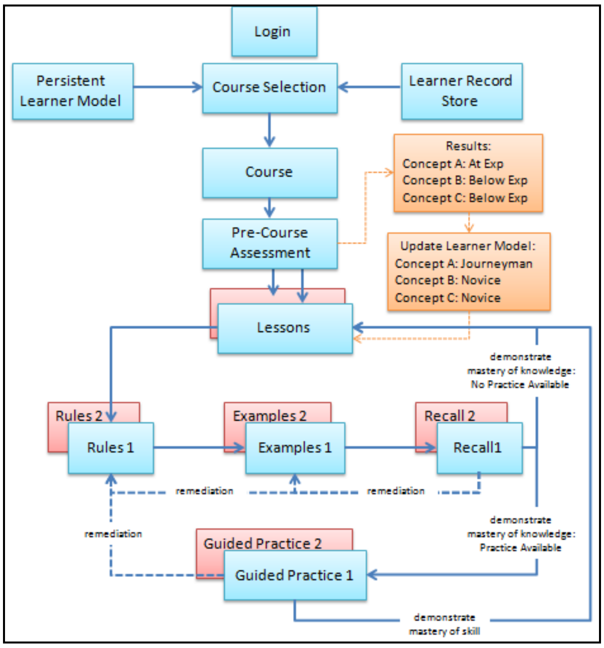

Figure 2: GIFT's EMAP

For outer-loop adaptive functions, components of the ATLEC are administered upfront to configure a lesson's sequence of interaction. Learner data informs strategy selections that associate with David Merrill's (1994) Component Display Theory (CDT). This interaction is currently encapsulated in a tool used by GIFT called the Engine for Management of Adaptive Pedagogy (EMAP; see Figure 2). In the latest GIFT baseline, the EMAP is used to guide a learner through a set of interactions that focus on: (1) the presentation of Rules for a domain or task, (2) the presentation of Examples where those rules are being applied, (3) the administering of a knowledge assessment that gauges a learner's ability to Recall facts, and (4) the administering of a Practice assessment that gauges a learner's skill for performing tasks associated with the domain of instruction (Goldberg & Hoffman, 2015). With a framework in place to support adaptive pedagogical modeling practices, work is required to identify a set of best practices for configuring the inputs and outputs of these models to optimize learning outcomes. To guide this research, requirements are defined that layout overarching instructional principles to inform pedagogical application and reasoning.

4. INSTRUCTIONAL MANAGEMENT END-STATE THEMES DRIVING RESEARCH

In the following section, we review the specific overarching themes associated with instructional management research in GIFT. Each theme is represented as a dimension of research that serves different components of the learning process. While reading through these research thrusts, it is important to conceptualize its application across various training environments and use cases. While these dimensions can be somewhat confined in terms of instructional management intent, how they can be applied across all types of training environments is vast. This includes considering individualized vs. team-based training events, as well as considering the technologies being applied to facilitate the training itself. With these guidelines, four themes will be presented. These include: (1) guidance and scaffolding practices, (2) social dynamics and virtual humans, (3) metacognition and self-regulated learning, and (4) personalization techniques based on cognitive and non-cognitive factors.

4.1. Guidance and Scaffolding

Scaffolding is a term used to describe the application of instructional supports to assist a learner in developing knowledge and skills that the learner would not achieve when left to their own devices. Holden and Sinatra (2014) define scaffolds as a temporary application of strategy that is gradually removed ('faded') once a learner demonstrates an increase in proficiency or skill. The word 'strategy' is used loosely here, as it can be a number of interventions that range from guidance, feedback, scenario/problem manipulation, and remediation. Prior to the advent of computer-based training environments and ITSs, an expert adult or peer (e.g., parent, teacher, classmate, teammate, etc.) provided scaffolding practices. This individual acted as an expert, a facilitator of KSAs required for learning, a motivator, a model, and a means for the learner to reflect (Puntambekar & Hubsher, 2005). As such, much of the applied guidance and scaffolding practices in adaptive training environments are based on what effective instructors and tutors do in real life. In examining models of expert human tutors, several themes have been identified for effective interaction:

- Demonstrate credible knowledge of the domain under training (e.g., tactical combat casualty care);
- Read cues from the learner and adapt instruction in real time to meet their changing needs;
- Encourage question asking;
- Provide indirect feedback;
- Assess learning often

When designing scaffolds and the logic associated with their execution, three dimensions require consideration. These are: What to scaffold, when to scaffold, and how to scaffold (Azevedo & Jacobson, 2008). With respect to GIFT, each of these dimensions must be conceptualized in a domain-agnostic fashion. The first consideration that will dictate how to proceed is based on available tools and methods for scaffolding. In this vein, the mode of interaction and the specific training application itself will determine what approaches can be implemented. For instance, interacting in VBS3 affords different scaffolding strategies when compared to interacting with a negotiation trainer on a tablet. The type of state (e.g., performance, affective, etc.) information being monitored in the learner model, the type of communication interfaces available for presenting information (e.g., GIFT's Tutor User Interface, Smartphone, Smart Glasses, haptic device, etc.), and the type of adaptations supported by the training application (e.g., changing the weather in VBS3 to increase the complexity of scenario) all impact the types of scaffolds that can be built to support a specific course or lesson.

Once you recognize the available tools to trigger and support scaffolding practices, determining what to scaffold must be addressed next. What to scaffold can be represented in a generalized fashion and is based on defined learning objectives and barriers to a learner performing successfully. This could include scaffolding specifically on the cognitive level that accounts for the domain or the task procedures themselves. Or scaffolds can account for different constructs associated with the learning process, such as metacognition (i.e., to regulate goal planning, performance monitoring, help seeking, etc.) and affect (i.e., to regulate motivation, boredom, frustration, confusion etc.; van de Pol et al., 2010). Recognizing what you want to scaffold along with what tools and methods you have to support those types of interventions will lend itself into building the specific scaffolds for implementation.

With scaffolds conceptually established, the next step is building logic for determining when to apply a scaffold and how to appropriately fade/adapt its use to promote efficient transfer of execution. A common perspective to account for this challenge is based on Vygotsky's (1978) ZPD. ZPD is an optimal and efficient zone of learning that elevates the student from his/her current and actual developmental level to one of more potential through balancing challenge with ability and through formative guidance to enhance skill. In its simplest form, the ZPD creates a formalized state space representation that enables a system to contextualize what a learner is experiencing for a given training domain. For example, if a training system launches a scenario with a preconfigured difficulty setting of expert and a trainee's skill state is defined as journeyman, the system may trigger specific scaffolds that are intended to support the maturation of skill levels to meet the challenge level of a selected scenario. In this instance, if performance assessments associate execution with increased skill levels, then the system must be able to recognize this shift and fade scaffolds. From the opposite end, if a learner demonstrates skills that fall below their predicted ability levels, the system must be able to appropriately trigger scaffolds to compensate for that inaccurate upfront classification. This must be possible for both dynamic scenario-driven tasks as well as for training applications that use discrete problem sets that allow adaptation between each problem.

4.2. Social Dynamics and Virtual Humans

In this research sub-vector we review end-state goals associated with the role of social dynamics and virtual humans in managing instruction within adaptive training environments. This line of research associates with tenets of Social Cognitive Theory in that learning is theorized to be an inherently social process (Bandura, 1986; Vygotsky, 1987). As such, techniques should be applied to account for high valued social elements that can potentially improve a piece of educational technology. In addition, Army task domains can involve highly socialized interactions. To support these task characteristics, adaptive training systems should account for the types of interactions a Soldier might face (e.g., negotiating with a village elder) and the variables that may influence their course of action (e.g., cultural norms for greetings and negotiations). From an adaptive training perspective, social dynamics and virtual human research is focused on:

- Using technology and AI to replicate interactive discourse common in educational and operational settings;
- Using technology to embed social elements in the environment, such as Virtual Humans, to create a social grounding function for delivering information/guidance;
- Using technology and AI to create realistic and reactive Virtual Humans as training elements in a simulation or scenario (e.g., role player, teammate, etc.);
- Using technology to create a social forum for the purpose of supporting peer-to-peer and collaborative learning, both from a real-time perspective as well as from a time-agnostic approach allowing interaction at convenience.

Each referenced focus area is based on a specific social element of interest to the GIFT community. Of importance is the application of these elements within the standardized architecture inherent to GIFT. Specifically, how can the tools and methods built to afford these capabilities be translated to support ease of application within any type of training event and within any type of training environment? Each identified element associates distinctly different research questions and associates distinctly different scientific disciplines. It is a very broad sub-vector of instructional management with many dependencies to other elements of the GIFT research program.

In the case of using ITS technologies to replicate interactive discourse, an end-state goal is to establish state of the art natural language processes to create a robust tool capable of dynamic Q&A exchanges. In this instance, we want a training environment to be able to push a question to a learner and we want a trainee to be able to ask questions of the ITS, ideally through natural language and open response input methods. As highlighted above, a characteristic of an effective tutor is one who encourages a learner to ask questions. This process in itself promotes learning through abstraction and reflection. As such, we need a discourse capability that can accurately interpret user responses, and intent, as it relates to the semantic space of instruction and we want this capability to associate with pre-existing training applications (i.e., use natural discourse Q&A in parallel with executing a VBS3 scenario). This capability can be applied in multiple training instances and under many conditions. This includes (1) discourse to support reflective Q&A sessions to promote higher order cognitive thinking, (2) discourse to support training events that involve social exchanges to meet certain negotiation objectives, and (3) discourse to support realistic communication with virtual entities in an environment that associate with both friendly and opposing forces. Much like scaffolding capabilities, the application of natural language discourse in an adaptive training event associates many dependencies across the various research vectors. Specifically, domain modeling, authoring processes and architecture requirements are the greatest considerations when it comes to implementing this approach to instructional management.

Next, virtual humans are identified as key technology pieces in extending adaptive training experiences to account for varying roles in the learning process. From an ITS support perspective, Virtual Human research is focused on the application of technology to provide an interactive communication layer that grounds all system generated prompts with a social element. An overarching intent is to facilitate interaction and communication with a computer in a way that is natural and realistic. The goal is to support highly engaging and interactive experiences through socialized sequencing of interaction and enhancing system communication by interfacing with a learner through comfortable modalities. Much of the prior research in this area focuses on the trust and perception of technology in facilitating a role traditionally managed by a person and the impact on motivation and effort (Kim & Baylor, 2006; Holden & Goldberg, 2011; Veletsianos, 2010; Veletsianos, Miller & Doering, 2009).

Virtual Humans can also facilitate critical role players in training events. In these instances AI methods allow virtual entities to realistically react to environmental stimuli and user inputs in a non scripted fashion, making the experience more natural and engaging.

Lastly, social media technologies are believed to offer innovative tools for instructional management practices that have yet to be fully taken advantage of. As a result, research is required to better understand how best those tools and methods can be applied.

4.3. Metacognition and Self-Regulated Learning

Self-Regulated Learning (SRL) theory describes the process of taking control of and evaluating one's own learning and behavior (Butler, Cartier, Schnellert, Gagnon & Giammarino, 2011). As a higher-order cognitive function, SRL is guided by metacognitive processes (i.e., the knowledge and regulation of one's own cognition), strategic actions and behaviors (i.e., planning, monitoring, and assessing one's own performance), and motivational components (i.e., goal setting and self-efficacy) (Flavell, Miller & Miller, 1985; Schraw, Crippen & Hartley, 2006). These functions allow self-regulated learners to set goals, monitor their progress toward defined goals, and adapt and regulate their cognition, motivation, and behavior in order to reach the specified goals (Anderman & Corno, 2013; Bransford, Brown & Cocking, 2000). These characteristics also associate with desired competencies within the Army Learning Model that adaptive training solutions are intended to instill. As such, research in the instructional management vector is focused on the application of models and strategies for enhancing metacognitive awareness and regulation.

This approach to instructional management varies from traditional guidance and scaffolding techniques as it focuses on behavior and application of strategy, rather than on task dependent performance. One such question is based around GIFT supporting SRL, and the efficacy of defining persistent metacognitive strategies that can be applied across domain applications. Currently, GIFT pedagogy is heavily focused on error-sensitive feedback. It works with system authors by translating instructional strategy recommendations communicated by GIFT's pedagogical module into tactics as they relate to the specific training context. These tactics are used during ITS runtime and are selected based on a learner's individual differences. At the current moment, feedback in GIFT is domain dependent and requires explicit content linked to each concept modeled. When it comes to metacognitive feedback, what are the implications to a domain-independent approach? First, modeling techniques need to be developed to monitor an individual's practice of metacognitive strategies that can be expressed in a generalized format. An example would be incorporating a combined modeling approach, as described in Biswas, Segedy, and Kinnebrew's (2014), or by adapting a help-seeking model, as highlighted in Koedinger, Aleven, Roll, and Baker (2009).

One such approach is researching and establishing models based around commonly available GIFT interactions (e.g., request hint button). How can we use these available data inputs to build a representation of how effective students use the interface to solve problems and troubleshoot errors? This approach can aid in detecting learners not practicing good metacognitive behaviors through machine learning and data mining practices and can be used to trigger feedback interventions to improve their understanding of available strategies. With modeling techniques in place, generic strategies and tactics can be identified that are based around effective metacognitive behavior. In this instance, the generic strategy of 'provide guidance' can be linked with a generic tactic of 'you are ignoring available resources', thus preventing any explicit authoring from a system developer. While tactics can be represented in a domain-independent format, their effect is relatively unknown.

4.4. Personalization (Occupational and Non-Cognitive Factors)

Current ITS systems, such as GIFT, offer more flexibility and features than systems and computer programs that were developed in the original context personalization research conducted in the 1980's and 1990's. Additionally, as a domain-independent framework, GIFT can be used to examine the impact of context personalization in a variety of other domains, whereas in the past the research has primarily focused on math instruction. One approach to context personalization research that can be taken with GIFT is to do work similar to Ross (1983), in which the context of the problems and materials are specifically matched or mismatched with the individual learner's specialty area. In the context of military training, a Soldier's Mission Occupational Specialty and near-term assignments can be used to personalize a training experience to better prepare that individual for the environment they will be operating within.

Rather than using mathematics as the domain of interest, a military relevant domain can be chosen. Providing materials that are matched to the individual learner's specialty area is expected to have a positive impact on learning and attitudes toward the experience. Learning outcomes are expected to be improved as the individual will not already have an understanding of the context of the provided examples, but also will be able to easily see why it is relevant to their own job.

In order to support personalization additional studies could examine the impact of allowing learners to select the context of the questions they will receive based on their own preferences or the task that they will be engaging in. In many military-related tasks there are subtle differences in the task that will be performed based on the geographic location of their assignment. For instance, if an individual is tasked with interacting and negotiating with individuals from a culture other than their own they may engage with a negotiation tutor. However, depending on the culture that they are to engage with there may be different phrases or customs that should or should not be used. The basic elements of negotiation will be similar, but the questions and materials can be edited to have geographic and culturally specific examples that will be more consistent with the actual experience the individual will have. Research can be conducted on the level and types of material and assessment personalization that results in positive outcomes and performance.

5. GIFT DEPEDENCIES IN SUPPORT OF INSTRUCTIONAL MANAGEMENT RESEARCH

Managing instructional strategy selection and tactic delivery is dependent upon multiple components of GIFT. This associates domain modeling to apply context to a pedagogical decision, learner modeling to provide trainee relevant information that triggers a pedagogical intervention, authoring to provide a means for building these linkages and representations, and training effectiveness to determine if a strategy or set of strategies had an effect on performance related outcomes. This highlights an important point; while each of the aforementioned components of instructional management has separate processes, the architecture is the component that dictates implementation design and development.

In GIFT, instructional management takes place in two modules/processes within the learning effect model. One process is instructional strategy selection within the pedagogical module. The second is within the domain module where specific tactics or actions are selected based on the strategy selection and instructional context. An important component of instructional management is translating a generalized strategy into a tactic that can be executed within a specific training environment. This requires understanding what knowledge components make up a domain and what tools are available to guide a learner and adapt the training event. In addition, domain modeling plays a critical role in enabling the use of reusable learning objects. When applying instructional management practices in an outer-loop capacity through GIFT's EMAP, a well-designed domain model can be used to identify content that can be presented to a learner along with data that supports its application. This supports ease of authoring as well, as a developer can leverage existing content if their domain model has overlap with existing course representations.

In terms of architecture, end-state goals of GIFT require potential integration with a number of technologies that facilitate varying roles of instructional management practices. These technologies include tools and methods to support content management, natural language processing, text to speech processing, virtual human authoring and configuration, social media framework connections, and training application manipulations (e.g., manipulating the weather in a virtual world). In addition, specific architectural modifications will be required to perform tasks inherent to the current standards of GIFT, including methods to create messaging templates used to auto-populate feedback scripts with context relevant information established in log files, the ability to personalize strategy selections on an outer-loop and inner-loop capacity across learners and teams of learners, and the application of actionable metadata and xAPI statements to appropriately link learner information and prior experience with appropriate training and optimized configurations. In dealing with a domain-agnostic intelligent framework such as GIFT, the use of machine learning and data mining techniques are required to reinforce and optimize pedagogical logic over time.

6. CONCLUSION

The foundational goal of adaptive training research at the ARL is to *model the perception, judgment, and behaviors of expert human tutors* to support practical, effective, and affordable learning experiences guided by computer-based agents. To this end, four primary themes in instructional management research for adaptive training systems were identified and discussed. This line of research is important to advance adaptive training solutions into a new state-of-the-art that optimizes training experiences through customized pedagogical practices.

Following the development of a pedagogical framework that accounts for these four themes of instruction, extensive empirical investigations will be conducted to validate their application across numerous domains of instruction. The results of these experiments will be used to refine pedagogical policies, with a goal of establishing reinforcement learning methods that automate modifications to the instructional strategy selection techniques.

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CONSIDERATIONS FOR LEARNER MODELING IN A DOMAIN-INDEPENDENT INTELLIGENT TUTORING SYSTEM FRAMEWORK

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ABSTRACT
This paper focuses on the learner modeling component of intelligent tutoring systems (ITSs). The majority of ITSs are domain-dependent with the domain content being closely tied to both knowledge about the learner, and the pedagogical strategies. However, the Generalized Intelligent Framework for Tutoring (GIFT) is a domain-independent ITS framework. This domain-independent advantage allows for significant reuse (instructional and learner models), reducing the amount of time it takes to generate ITSs. It also creates interesting challenges and considerations that need to be taken into account when determining what elements need to be included in the various ITS modules. While GIFT currently includes a learner module component, additional research is expected to be conducted to determine the ideal components to include in GIFT's learner module. The current paper discusses the unique challenges of developing domain-independent learner models, as well as concerns related to implementing and authoring.

Keywords: adaptive and predictive computer-based tutoring, adaptive training, learner modeling, intelligent tutoring systems

1. INTRODUCTION

Intelligent tutoring systems (ITSs) provide personalized and adaptive tutoring to individual learners. While classroom based learning has been the norm for many years, it is often difficult for students to get personalized attention, due to large class sizes. ITSs can be used either as a supplement to classroom learning, or as a primary means of learning. Allowing a student to engage with ITSs independently leads to a higher reliance on self-regulated learning, where individuals manage the pacing of their own learning. There are a number of strategies that lend themselves to successful self-regulation of learning, however, not all students spontaneously engage in them (Zimmerman, 1990). Therefore, one goal of ITSs are to provide information to students in such a way that they will be engaged with the system and exhibit patterns of interaction that will lead to long term learning gains. In order to lead to engagement, it may be useful to customize materials to the specific learner's characteristics, experiences, or current mood. In order to customize instruction it is important for the ITS to have a representation of the learner's state, which includes affective state (e.g., mood), as well as cognitive, and procedural assessments of the learner that are relevant to the domain area of interest (Pavlik, Brawner, Olney, and Mitrovic, 2013; Woolf, 2010).

1.1 Traditional ITS Components

ITSs traditionally have four software modules: the learner module, pedagogical module, domain module and tutor-user interface (Sottilare, Graesser, Hu, and Holden, 2013). The pedagogical module is responsible for the instructional strategies that are provided to the individual learner. The domain module is specific to the domain information (content, lessons, subject matter, etc.) being tutored. Naturally, the tutor-user interface is the way that the learner interacts with the system. The learner module is the software process where all the information about the individual learner (learner model) is stored and processed. It represents the previous knowledge about the learner, the current knowledge of the learner's state, and is traditionally updated throughout the learner's time engaging with the ITS.
In current terminology, a software "module" refers to an executable piece of software, running as a part of a total system. A "model" refers to the data and processes which run inside the module. As an example, a simplistic learner model may blindly communicate underperformance whenever it is made aware of it; this underperformance information would, of course, be communicated by a software module to other modules containing their own models of instructions.

1.2 The Generalized Intelligent Framework for Tutoring

The Generalized Intelligent Framework for Tutoring (GIFT) is a domain-independent framework that provides individuals with the ability to create ITSs, deliver training, and analyze data. The modules present in GIFT are similar to those of traditional ITSs; GIFT has a learner module, domain module, pedagogical module, sensor module, and a tutor-user interface (Sottilare, Brawner, Goldberg, and Holden, 2012). The addition of the sensor module provides assistance in measuring learner variables, and assists in updating the current state of the individual learner model, which is in the learner module (Sottilare, 2012). The development of GIFT's architecture is consistent with the Individual Learning Effect Model (Sottilare, 2012). Figure 1 shows the most recent version of this model. The learner model contains individual learner measures and states, which influence the instructional strategy that an individual receives. This strategy becomes an "instructional tactic" when it is implemented within a domain of instruction, the distinction being the addition of actual learning content. After the instructional intervention is received the performance of the individual learner updates the learner data and the state of the individual. This information will then once again influence the instruction that the individual receives. Therefore, the information about the learner's state drives pedagogy, which then drives the learner's state.

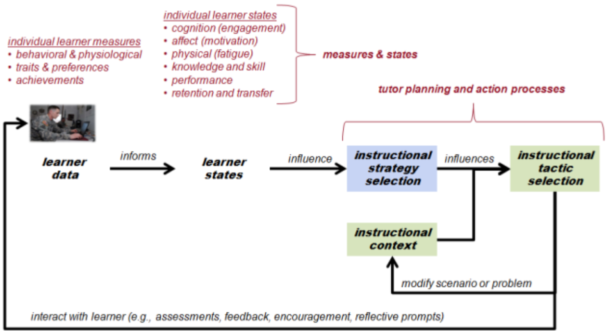

Figure 1: Individual Learning Effect Model

While the GIFT architecture contains these components, the framework and software itself are still under active development. The functionality that is currently in GIFT will expand as GIFT continues to be developed and improved. As GIFT is an open-source project, the needs of the user base can influence the directions taken for future design decisions.

The current paper discusses the unique considerations in the development of a domain-independent learner model, highlights the supporting technology that can interface with the learner module, and discuss approaches to authoring. Additionally, the paper discusses future directions that can be taken in adding additional functionality to GIFT's learner module.

2. CONSIDERATIONS FOR DOMAIN-INDEPENDENT LEARNER MODELING IN GIFT

Traditionally in ITSs the learner module contains information about the individual learner who interacts with the system. While learner models that are used in different ITSs have much in common, they are generally unique to the development of the individual systems. Most ITSs are domain-specific, and are further designed to teach one specific well-defined domain, resulting in the majority of ITSs being for instruction in mathematics and physics. This is partially a function of demand, and partially a function of the relative difficulty of developing an ITS for well-defined as opposed to ill-defined problems (Sottilare and Holden, 2013). For these domains, the author of the ITS decides what learner assessments are useful and relevant to the instructional domain when creating the learner model. In the case of mathematics this may include prior math courses taken, grade point average, and scores on relevant standardized tests. It might also include factors like the learner's intelligence, metacognitive skills, conscientiousness, and grit. As can be seen, some of these attributes are domain dependent (e.g., prior relevant coursework, previous performance) and others are domain independent (e.g., intelligence)

Using GIFT's domain-independent framework has both challenges and advantages. The advantages include the reusability of the authoring tools, content, and portions of the created ITS. Additionally, questions and assessments that are authored in the domain-independent ITS can be edited and used as a foundation of other courses. These advantages also lead to a savings of money, as new systems do not need to be developed for every type of ITS course that is generated. When developing a domain-independent architecture such as GIFT, a challenge is to create a learner model flexible enough to work with any domain. One challenge is in determining ways in which domain independent learner attributes can be used to adapt training across domains. For example, learner intelligence may be used to adjust the difficulty or pace of the training. Another challenge is determining ways in which assessments of the learner's past experiences, training, assignments, goals, and interests can be collected from existing data sources such as personnel, training, and learning management systems. For example, college transcript grades could potentially be utilized to help determine the difficulty level of current training that should be assigned. Currently, GIFT is limited to collecting this kind of information about the learner at the beginning of a course. However, it is not practical to collect this amount of information from learners each time they start a new course. Automating the process of collecting that information when a learner begins training will both improve the learner's experience by reducing or eliminating lengthy pre-training surveys and will facilitate the development of predictive models of learner performance and training effectiveness.

2.1. Domain-Independency and Time of Assessment

There are two main types of assessments that are commonly supported by learner models: pre-training assessments, and in-training assessments. Further, these types of assessments can be further sub-divided into domain-dependent and domain-independent categories. The following sections describe current features of GIFT, and ways that these assessments can be accomplished using GIFT.

2.1.1. States vs. Traits

Psychologists generally distinguish between states and traits. While not strictly the same thing, ITSs distinguish between long-term and short-term learner models, and these terms have previously been used in the context of ITSs (Pavlik, Brawner, Olney, and Mitrovic, 2013). States are short-term and specific to how the individual is currently feeling or performing (i.e., the short-term learner model).Traits are associated with longer-term characteristics, such as an individual's personality scores (i.e., the long-term learner model). While there may be some variation in the mood of an individual that will fluctuate from hour to hour or day to day, an individual's overall level of neuroticism is not expected to shift dramatically in a short period of time. In the context of adaptive tutoring, competencies and aptitudes are relatively stable "traits" that are generally assessed pre-training, and are used to make decisions about the type of material the learner will receive. Further, "state" measures, such as the learner's current mood, or current performance have an influence over in-training materials that are provided and update the learner model while the learner is actively engaged with the tutor. Figure 2 is a proposed assessment framework for a learner model, which accounts for both domain-independent, and domain-dependent components, and serves as a basis for our discussion of learner modeling.

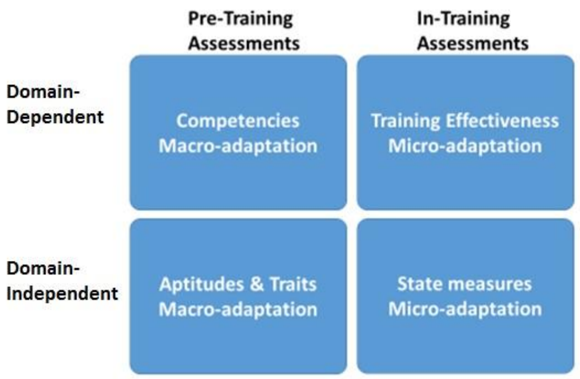

Figure 2: Assessment framework for a learner model

2.1.2. Pre-Training Assessments: Questionnaires

In an ideal training environment, there are stable characteristics of a learner that might influence the type of training that the learner is given. In the ideal learner model all of the learner's relevant scores, questionnaire data, and survey data would be stored. This information could be gathered from existing records, or if a relevant score is missing the learner could be prompted to take a survey or provide information that would update their learner model. Further, rather than having the learner repeatedly take a survey like a personality test or a working memory assessment, which is time-consuming, the output scores should be stored for later retrieval for the learner model. This information could then be referenced in the future for making of pedagogical decisions between different instructional strategies. In current implementations of GIFT, survey outputs and scores are associated specifically with courses that have been developed, as opposed to being associated with the individual learner, but it would take little overall work to retrieve them for future use in new courses.

Questionnaires are very useful in measuring information that could be of interest in instruction (e.g., reading level, working memory, special ability). These scores are unlikely to change and by storing them it could improve the ITSs ability to adapt to the individual. Further, by storing interest preference based information that could be gathered in surveys it would allow for additional opportunities to customize instruction to the individual. If more detail is stored about the individual learner it can lead to more accurate selection of relevant instructional strategies, and better learning outcomes.

2.1.3. In-Training Assessments: Sensors and Questionnaires

There various ways that state of the learner can be assessed during training in order to make adjustments to the materials the learner is receiving. In GIFT, the current state or performance of the individual is received from the learner, and then used to update the learner model. Sensors are primarily a state based measure, which measure real-time information such as attention that can change relatively quickly. Input from the sensors in GIFT is provided to the learner module, which updates the current state of the individual in the model it contains. There are a number of different sensors currently integrated with GIFT, including the Microsoft Kinect (which can examine movement and provides camera tracking) and the Q-sensor (which measures skin conductance, a proxy for anxiety). The information provided from these sensors can help to determine the individual learner's current affective state (Paquette, et al., 2015). While sensors are a passive way of determining state, which in general are not disruptive to the flow of a tutoring session, they can sometimes be difficult to work with in real-time. Many considerations have to be put into place in order to provide state adjustment based on sensor data, and calibration of sensors may be difficult or unrealistic in distance-learning environments. An additional way of determining the current affective state of the learner is through direct user query, such as the Self-Assessment Manikin (SAM) survey (Bradley and Lang, 1994), and through asking individuals to rate their mood. This method is not without its drawbacks, as it can disrupt the flow of the tutoring and is reliant on the learner's own self-assessment. However, surveys and questionnaires are a relatively stable way to get information about the learner's state that can be used for adaptations in learning material.

2.1.4. Domain-Dependent vs. Domain-Independent Assessments

In the case of both pre- and in-training assessments, there is domain-dependent and domain-independent information that is useful for adaptation. Traditional ITSs are tied to one specific domain, therefore, all of the data that they store in their learner model has been selected to cover relevant information for the specific context. However, in a domain-independent framework, it is necessary to include domain-independent measures that are relevant for a number of different domains, and provide the ability for authors to incorporate the measures that they wish to use for their assessments. For instance, reading level is domain-independent, but is relevant for numerous domains including: reading comprehension, math, physics, and computer programming. Another example is spatial ability, which is highly relevant for a number of domains including navigation, mental rotation, and drawing. However, in the case of domains such as math, spatial ability may not be as relevant and the learner model should provide the author the flexibility to select the elements that are relevant to the domain of interest.

In the current default state, GIFT's learner model tracks state data such as anxiety, boredom, confusion, and surprise. Additionally, it can adjust based on trait data such as locus of control, learning style, self-efficacy, grit, and goal orientation. However, the learner model is flexible and can allow for authors and researchers to follow and adjust based on specific states of interest in their specific domain. This is advantageous as it allows for customizable tutoring, as well as the ability to conduct experiments that examine what learner model elements are relevant in the domain of interest.

2.1.5 Competency Measurement

A major challenge for any ITS is the development of learner competencies. Competency is the set of knowledge, skills, and abilities that comprise competence in a specific job or role. Competencies develop over weeks months or years. To date, learner models have not typically incorporated competencies into their frameworks. Competencies are generally domain-dependent, and can be used during pre-assessment to adapt the materials that the learner receives.

2.2. Performance

The performance of the individual as they engage with the ITS is also an important component of the learner model. This performance is generally domain-dependent, and in the case of GIFT, while the learner model remains domain-independent, the domain model provides the information to the system to make sense of the learner performance in context. There are a number of different strategies that can be implemented to establish the learner's current domain-dependent performance state, as compared to the ideal learner state. Among these strategies are using overlay student models (e.g., rule space student models, model tracing student models), knowledge space models, and dialogue student models (Pavlik, Brawner, Olney, and Mitrovic, 2013). The learner's established state influences the pedagogical and instructional strategies that are selected for them. Once they have engaged in their interactions with the system their performance can inform the learner model and update their knowledge state. Therefore, the performance of the individual within the tutoring environment is clearly an important component of learning modeling.

2.3. Supporting Technology

There are a number of supporting technologies in order to capture, store, and utilize learner information. The basic types of information which are interchanged by GIFT are information of performance, captured with system assessments, as well as state and trait information, captured via sensors and surveys. This information is stored in log files for processing, and, depending on its nature, reported out to various external systems. A brief synopsis is included below.

2.3.1 Assessment

GIFT includes features which allow for the assessment of learner mastery of individual concepts for instruction. All of GIFT's modules are domain-independent except for the domain module. For instance, the learner module includes general statements about the learner, and the pedagogical module includes general instructional strategies. In GIFT the link is made between these general statements and the domain-specific content by the course author. The first of these links is the Domain Knowledge File (DKF). In the DKF, the course author provides assessment logic which defines messages in terms of the domain, and allows the Domain Module to receive messages which are passed to it using pre-coded interfaces. For instance, the pedagogical module may indicate that the strategy of "provide feedback 1" should be used. The DKF is where the author will make the connection that "provide feedback 1" should say "Make sure that you are using the correct order of operations: Add, Subtract, Multiply, Divide." The DKF provides the link between the general and the specific in GIFT's domain-independent framework. Further, the DKF defines concepts and the level of achievement the learner currently has based on performance (above expectation, at expectation, below expectation). Specific feedback and actions can be taken as a result of changing to different performance states. Examples of this assessment are demonstrated in courses included with GIFT software releases that interface with PowerPoint (assessing dwell time on slides), and in VBS2 (assessing individual markers).

The second manner in which performance is assessed is through the use of an external assessment engine. In this instance, the DKF simply indicates that messages of a certain type should be forwarded to another engine for assessment. An example of the use of this type of external engine can be seen in the SIMILE engine, used for vMedic training, and its authoring tool which is included with the GIFT software.

2.3.2 Log files and Databases

For the purposes of experimentation and evaluation, GIFT records nearly every transaction as part of its log files. Given that each of these messages is effectively stored for long term analysis, there is a tool for the extraction of specific elements within this sea of data. The Event Reporting Tool (ERT) allows for the extraction of key items of interest within a training scenario.

In addition to this storage, there is an amount of information which is stored within a database (mySQL, or Derby, depending on configuration) for later use. Examples of information which is stored include learner trait information, survey entry values, and “scored” information from interactions within an environment. The latter portion of this data is used in a simple course recommendation engine, which recommends courses based upon unsatisfactory completion.

2.3.3 Learning Record Stores and xAPI

Information which is stored within this database is additionally communicated externally to a Learning Record Store, using the xAPI encoding. xAPI is a manner of encoding learner “experiences” for the provision to other systems in the “subject verb noun” fashion. An example of an English xAPI statement would be that “John Mastered Italian”, each of these objects has supporting field information (email address for John, wordnet definition of mastered, competency ontological link to Italian). Further information on xAPI statements can be found at http://www.adlnet.gov/expapi/.

xAPI statements require a storage location, which is the key feature that allows various systems to output xAPI information into a central repository which can be read from and written to. Because of the standardization of the xAPI statements, a wide variety of Learning Record Store (LRS) systems have been created, many of which have built from the Advanced Distributed Learning (ADL) open source reference implementation. Further information on xAPI statements can be found at http://tincanapi.com/learning-record-store/, which also provides a freely available and hosted LRS implementation.

GIFT makes use of both of these technologies in simplistic fashion. It rephrases its traditional score reporting to be compatible with the xAPI standard. It redirects its learner information to an LRS instead of a simplistic database. Each of these technologies has the potential to read and write much more data than is currently being broadcast.

3. AUTHORING CONSIDERATIONS IN A DOMAIN-INDEPENDENT INTELLIGENT TUTORING SYSTEM FRAMEWORK

Creating authoring tools that are domain-independent is a unique challenge. The tool needs to be easy to use, but also general enough that it can be used by individuals of varying skill levels and experience. GIFT includes a number of different authoring tools that have been structured to allow for the authoring of courses, and models that are not specifically tied to any one domain. Surveys and questionnaires are authored in the Survey Authoring System (SAS), which provides many of the features that are standard in survey creation utilities. These surveys are domain-specific and can be associated with specific courses by the author using the GIFT Authoring Tool (GAT). GIFT provides editing capabilities for the different models including the learner model, sensor model, and pedagogical model. The course author can include the components of the learner model that he or she feels is relevant for their specific ITS. Additionally, if the author would like to conduct research into which elements are relevant in their domain they can quickly swap out the tracked/adjusted for elements with little work. The DKF authoring tool allows for the linkage of general material to the specific domain. The author defines the different concepts that will be monitored, and then associates different types of feedback with transitions that happen based on performance. Once all of the modules are configured and all materials have been gathered, the author creates their overall course flow which references domain-specific materials and training applications (e.g., VBS2, PowerPoint). See Figure 3 for a screenshot of the GAT in GIFT 2015-1.

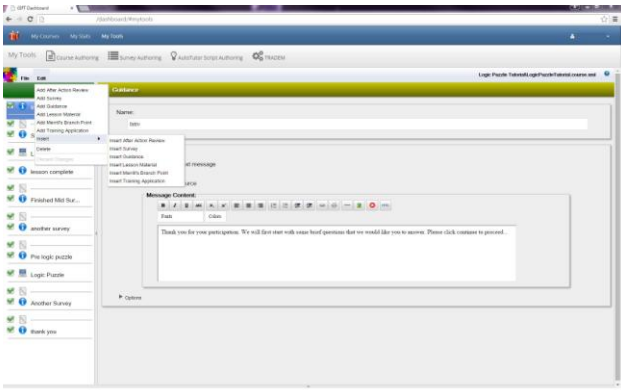

Figure 3: Interface for the GIFT Authoring Tool. After configuration has been done, this authoring tool combines both the domain-independent and domain-dependent components into one course flow.

4. CONCLUSIONS

The learner module is a traditional component of ITSs. However, it is also traditionally very tightly coupled with the domain being tutored. This provides challenges in ITS development in a domain-independent intelligent tutoring framework such as GIFT. However, it also provides the ability to separate the pedagogy, learner state, and the domain of interest. By doing so it allows more flexibility in the development of the ITS system, and promotes reusability. Further, it provides a way for researchers to compare the relative benefit of including specific elements in their learner models and conducting experiments.

Future directions of research intend to further expand GIFT's learner modeling into the area of teams and assess what elements should be examined on the team level, individual level, and at both levels. Additionally, as GIFT's domain-independent framework continues to mature it would be relevant to assess how much time it takes to author learner models and associated domain-dependent materials. This line of research could further refine and inform the process that is used in GIFT to create learner models. Learner models are an important part of any ITS. It is important to consider the benefits and challenges of developing domain-independent learner models which are reusable, interoperable, and allow for easy editing.

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ARCHITECTURAL RESEARCH IN INTELLIGENT TUTORING TECHNOLOGIES

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ABSTRACT
It is well known that personalized and adaptive training, such as from a human tutor, is dramatically more effective than traditional classroom training. Due to reasons such as cost and availability, however, most military training is still provided in the traditional classroom format. The United States Army Research Laboratory has recently published research plans and major thrusts for changing this dynamic. Each of these research plans outlines a different aspect of intelligent tutoring system technology, which are tied together in a unifying architecture for conducting the research. This paper discusses how this path was decided upon, the progress made to date, clarifies the role of the architecture in the research, and discusses some of the advantages of a unified system as part of measuring training effectiveness and overall system improvement.

Keywords: Adaptive and Predictive Computer-based Training, Intelligent Tutoring Systems, Architectural Components, Emerging Standards

1. INTRODUCTION

The United States (US) Army Research Laboratory (ARL) has developed a program of research called adaptive training which includes six interdependent research areas or vectors: individual learner and unit modeling, instructional management principles, domain modeling, authoring tools and methods, evaluation tools and methods, and architectural and ontological support for adaptive training (Brawner et al., 2015). Each of these research vectors has its own objectives, challenges, and research goals. In addition to these vectors and project teams, ARL has been researching and developing a common architecture for the capture of research outputs of various projects, which is known as the Generalized Intelligent Framework for Tutoring (GIFT) (Sottilare, Brawner, Goldberg, and Holden, 2012). GIFT consists of a series of software modules which are able to interface through a messaging standard. The modules are: the learner module, sensor module, pedagogical module, and domain module. The interactions between these modules form a significant portion of the base for the research vectors.

In both the literal and philosophical sense, software architecture has pragmatic purpose and serves a supporting role. As such, the primary function of the "architecture" component of the Adaptive Training group is to support and extend the abilities of the other active areas of research. This is performed through the capture of research performed in other vectors, functionality given to specific vectors, and through the practice of standardization within communication. This paper will discuss the history and origin of the GIFT project, the current direction which it is going, the key components of its implementation, the major architectural research and development challenges, and the opportunity for the international community to contribute.

2. A BRIEF HISTORY OF GIFT

The current progress in GIFT has been slow, but steady. Since its first inception, GIFT has been used in many training domains. These domains range from an unpublished, very simple, addition tutor, to a complex vMedic game-based scenario that monitors performance and offers adaptive feedback. The vision for such a system was documented well before its realization in software as a special report of its functions and intended functions (Sottilare et al., 2012).

Initial versions of GIFT were prototyped in developmental fashion, with a complex setup process that required end-users to set JAVA_HOME variables, install mySQL, and other items which would be typical for developing on a software-intensive project. Based upon feedback, the project has gradually expanded its group of intended users to range from software developers to educational psychologists to military instructors. As a byproduct, the installation process has been greatly simplified into a single "batch" file, which includes no individual variable manipulations, and requiring no administrator privileges. Therefore, the installation procedure is now similar to the experience of clicking "install" that most users are familiar with. Further improvements to the difficulty of configuring GIFT content has resulted in the development of XML-based authoring tools, which have developed into more user-friendly, graphical user interface-based versions, which are currently available. These improvements generally mark the beginning of the transition of the project from a development tool to a user tool.

The project has a three-tiered approach to developing appropriate supporting features for the needed user functionality. At the first tier, GIFT development has been steered by an executive committee, conducted as a series of yearly advisory boards. The output of these advisory boards is a published book that documents the board's generalized architecture recommendations on subjects such as the authoring tools, learner modeling, and instructional strategies (Sottilare, Graesser, Hu, and Brawner, 2015; Sottilare, Graesser, Hu, and Goldberg, 2014; Sottilare, Graesser, Hu, and Holden, 2013). At the second tier, there are a series of approximately 8-13 Government-managed projects which investigate various aspects of using GIFT. These project topics include utilizing sensor data information, generalized instructional engine development, and integrating and testing functions of other tutoring engines, such as AutoTutor. At the third tier are the critical individuals and organizations that develop GIFT modules instantiations, write plug-in code, conduct empirical evaluations, run studies, and are involved in other aspects of development. These three tiers operate together, from a program management perspective, to create functioning software based on well-informed recommendations, research findings, implementation, and testing.

The first version of GIFT (GIFT 1.0) was released in May of 2012, and was followed by various releases at the times shown on Table 1. Each release, so far, has contained a new domain of instruction, which is also backward compatible with previous releases. These domains of instruction include room clearing tasks inside of a VBS2 environment, tactical combat casualty care from a vMedic environment, or simply performance monitoring inside of a PowerPoint environment. Each of the courses associated with these environments have been made freely available to the general public, and are included with GIFT releases. The authors encourage the reader to download the GIFT software and examine them.

Table 1 - GIFT Releases and Versions

Version	Release Date
1.0	05/2012
2.0	11/2012
3.0	05/2013
4.0	11/2013
2014-1X	04/2014
2014-2	09/2014
2014-3X	12/2014
2015-1	06/2015

At the time of writing, GIFT has over 550 users who have registered for accounts on the www.gifttutoring.org portal, and has achieved modest technology transition into the field of use with a joint project with both the US Navy and US Army. This adoption rate has been steady, with numbers increasing each month and year, despite programmatic difficulties involved with decreased spending by acquisition agencies and limited conference travel among the scientific agencies.

GIFT has served as a basis for much of the US Army's research with adaptive tutoring. The expansion of the program to involve additional personnel, and the expansion of each of the research vectors has resulted in the development of a carefully constructed plan to avoid overlap, continue in a unified direction, and provide the functionally separate components that have been intended and designed towards at the outset of the project. Generally speaking, as an active research project, many existing training domains and tasks have been integrated, with new training environments emerging with each additional project need. Table 2 describes training environments to date that have used GIFT, which have been created or tested in support of the US Army's vision for learning in 2015.

Table 2 - GIFT Use in Training Environments

<Company/Organization>	<Type> Training
Learning in Intelligent Tutoring Environments (LITE) Lab	research with memory/retention, marksmanship
Dignitas Technologies	proof of concept in VBS2, medical, COIN
Stanford Research Institute SoarTech	Situational and cultural awareness
Eduworks Corporation	IRB, math, medical
Engineering and Simulation Systems	medical
Florida State University University of Memphis	Physics
Iowa State University	small team training in VBS2
Intelligent Automation Incorporated	COIN operations in UrbanSim
CHI Systems	various among previous (interoperability)
Institute for Creative Technologies	situational pedagogy (for other training)
Problem Solutions Aptima	gunnery training, proof of concept interoperability
Naval Air Warfare Center - Training Systems Division	cryptography equipment
Army Research Laboratory	Civilian Affairs operations
Carnegie Learning and TutorGen	mathematics
Dignitas Technologies, commercial sales division	regulation compliance, driving simulators
United States Military Academy at Westpoint	engineering decision processes
Program Executive Office, Simulation Training and Instrumentation	Marksmanship

3. THE US ARMY LEARNING MODEL

The Army Learning Model/Concept of 2015, originally published in 2011, has served as a motivation for the development of GIFT. Portions of this Model/Concept have now been implemented, but there are still unaddressed requirements. The implementation of the Model/Concept is tasked to the acquisition commands, which leverage the research community to mature the underlying technologies. The authors would like to refresh some of the key concepts in Figure 1, with the knowledge that each of the research vectors is attempting to introduce adaptivity across all objectives:

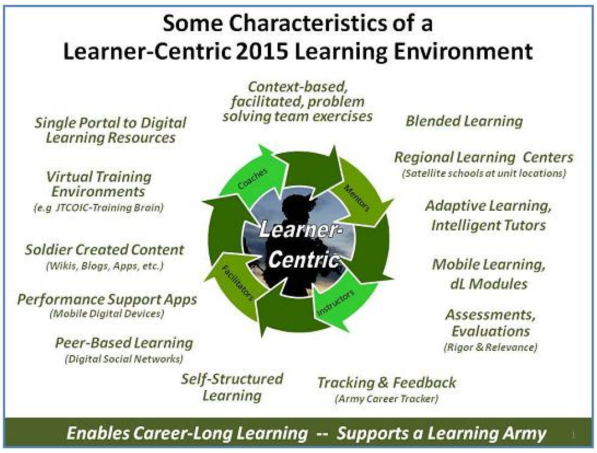

Figure 1: Army Learning Model (Army, 2011)

Some relevant portions of this combined learning picture are: tracking of a total career, digitizing nearly all learning resources, and the prevalence of "continuous learning" environments. A continuous learning environment consists of a training environment which is linked to the tactical equipment (embedded training), a virtual environment/campus, and to refresher training on mobile devices, following the general idea that training will be available anywhere at any time.

Regardless of the environment and delivery system, each of these training experiences should be adaptive and personalized in order to promote learning. Adaptive, in this sense, means responsive to the actions of the user: correcting misconceptions for a cognitive task (e.g., troop placement), or correcting performance errors for a psychomotor tasks (e.g.. marksmanship). Personalized, in this sense, means that the content has been customized for the user who is to receive it. As an example, a user with low motivation may receive material that is highly interactive, as managed by an instructional engine (Goldberg et al., 2012). These decisions are output as data from the modules which make them, and are reliant upon the input data which they receive from other models. The management of this data is shown abstractly as offline and online processes in Figure 2. The Army Learning Model provides a vision of the future, while the following section details the status of the present and paths created to get there.

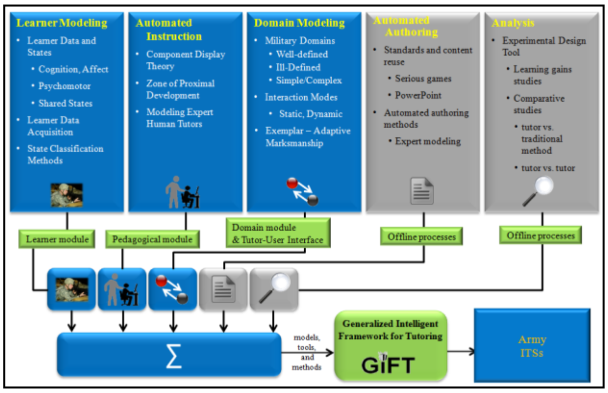

Figure 2: Adaptive tutoring research vectors. (Sottilare, 2013)

4. COMPONENTIZED APPROACH TO RESEARCH AND ARCHITECTURE

One of the authors, in 2010, had the privilege of working with a successful military ITS known as the Tactical Action Officer (TAO) ITS which illustrates the current state of ITS system design (Stottler and Vinkavich, 2006). The system was designed to have computer "virtual role players" take the place of live human instruction, such that a 6-man team could train with only one man present. It was designed with a scenario generator to replicate military scenarios that were of interest, in order to stay relevant in modern military environments. Lastly, it was shown to modestly increase learning in unscientific study, which was not particularly a project goal. The following story of this project provides an illustrative example of the state of the art at the time as well as portions of the guiding design principles behind the GIFT architecture currently.

While this ITS was useful for military training purposes, through elimination and reduction in the number of required instructors, the shortfalls of the field can be seen through the process of its design and support. Firstly, such a system was selected, in open proposal, based on the partnership of an ITS company and a defense contractor; the resultant system required the expertise of instructional designers and subject matter experts in addition to the traditional development staff. Such partnerships, although well structured, should not be required to build a training system; *there should be a platform which encapsulates the current state of the science in an existing system for experimentation and use which can be implemented as a traditional engineering "black box"*.

Next, the schoolhouse which was the recipient of the system wanted to adjust the content. Although an authoring tool was developed for the effort, it created new scenarios for the existing assessment rules to be applied: no change could be made to the assessment logic or provided feedback. Changes in military policy and practice necessitated changes in the system, which then required both instructional knowledge and programming knowledge in the type of partnership described earlier. *The system should be able to readjust its assessment logic without reengineering*.

Further, the Navy schoolhouse found the technology useful, as it made the task of instruction easier through the automation of part of it. The training system program was expanded to include instructional content for the Ship Self Defense System (SSDS). It was found through practice, however, that it was impossible to take the existing instructional models and task assessments from one domain of instruction (TAO) and apply them to a new one (SSDS). This re-crafting of the resultant system was nearly as expensive as the creation of the initial system. *A modern ITS should be able to be repurposed for new tasks on an existing simulation without the reinvention of the system itself*.

Finally, the TAO ITS system required updates to some of its core functions. These updates fell into two general categories: information assurance improvements, and new capability improvements. The information assurance improvements were relatively straightforward, as most modern software systems are designed for ease of maintenance. The modest capability improvements, however, proved difficult, due to the closed and tightly coupled nature of the product requiring member of the initial construction team. *Open architectures are needed to facilitate long-term logistics cost of software*.

The lessons here are relatively clear, and have been learned both in other industries (e.g. car manufacturing) and within the computing industry (e.g. operating systems and drivers): common architecture and reusable components reduce time and cost. Specifically, the architecture for a common learning system should be able to encapsulate the knowledge of the supporting roles such as instructional designers and student models. Components should not be tightly coupled, but loosely integrated, such that individual portions (e.g. assessment logic), can be changed without programming. The architecture should include, as one of these components, a single model of the domain, such that it can be replaced with another domain of instruction for a "new" tutoring system. Finally, the interfaces and data to such a system should be clearly defined in order to create sustainable systems, or to be easily updated.

In response to the needs detailed above, ARL has an ongoing program in adaptive training that is contributing to the state of the art in tailoring training along six research vectors (Figure 2) in support of the US Army Learning Model (Section 3):

1. individual learner and unit modeling
2. instructional management principles
3. domain modeling
4. authoring tools and methods
5. evaluation tools and methods
6. ontological and architectural support for adaptive training

The first vector, individual learner and unit modeling, aligns with and supports both the "individual learner" and "social learning" subsections of "innovation in learning". In this area, we are researching the effect of transient (e.g., near-term learner states including performance), cumulative (e.g., achievements, competencies), and enduring learner characteristics (e.g., personality, gender) on instructional decisions and outcomes (e.g., learning, performance, retention, and transfer). This includes a recently completed literature review of the team performance and tutoring. We are developing team-level state models for team processes (e.g., coordination, communication, and leadership) and emergent team states (e.g., cohesion and conflict) based on their effect on performance and learning in the literature. These models will be validated in team training environments. There is also a developed social media framework as part of GIFT to support the acquisition and evaluation of user-generated content. This research focused on data analytics to support continuous improvement of instructional content, methods, and tools to enable the practical development and use of adaptive training systems.

The instructional management principles for adaptive training are based on the learning effect model and learning theory, shown in Figure 3 (Sottilare, 2012). The engine for managing adaptive pedagogy (EMAP), the default pedagogical module in GIFT, currently supports an instantiation of Merrill's component display theory derived from Gagne's 9 instructional events (Goldberg et al., 2012). The basic driver behind this theory is that there is the presentation of Rules, Example, Recall Practice, where each item builds on the previous items. A summary figure presenting this research is displayed in Figure 3. The work in this area is primarily focused on developing methods for optimal strategy selection based on learner states. The selected strategies drive selection of tactics or actions by the domain module.

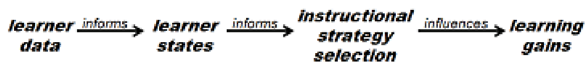

Figure 3: Learning Effect Chain (R Sottilare, 2012)

Domain modeling for Adaptive Training focuses on the representation of knowledge for a particular task or concepts and includes: relationships between goals, learning objectives, concepts, and learner experiences, domain content (a library of scenarios or problem sets); an expert or ideal student model with measures of success; and a library of tactics or actions (e.g., questions, assessments, prompts, and pumps) which can be taken by the tutor to engage or motivate the learner and optimize learning.

Authoring Tools and Methods focuses on research to reduce the time, cost, and skill required to author adaptive training systems. This includes the development of standards to support reuse and interoperability among these systems, interface specifications to support easy integration of existing systems, and automation to reduce or eliminate the authoring burden (e.g., expert model development, and scenario evolution based on a single parent scenario).

Evaluation Tools and Methods focuses on reducing the time and effort required to evaluate the effectiveness of systems, components, tools, and instructional methods. While this area is much broader than adaptive training, it is being specifically applied to adaptive systems as a use case. Items such as automated tools, long-term analysis, behavior change effects, and retention are being addressed from this perspective.

Lastly, the Ontological and Architectural Support for Adaptive Training is focused on standardizing terms, functions, components and their relationships to support modularity, access at the point of need, and the vectors noted above. GIFT is the prototype being developed to capture all we are learning in this area, and has garnered interest from both the US Chief of Staff of the Army's and the US Chief of Naval Operations Strategic Studies Groups.

5. CONTENT AND INTEROPERABILITY

By far, the most difficult design consideration for the GIFT architecture is how to be, and remain to be, domain independent while still contributing something valuable to an individual system. Providing such an architecture requires the removal of much of the context behind performance, and the generalizing of instructional strategies. Information such as when and how to provide feedback is domain general, but information which involves specific mistakes or corrections must be handled by an interchangeable module. To support this end, the Domain Module has a few specific pieces of information made available to it:

- A concept/subconcept hierarchy of the tasks which should be instructed in an individual course
- A link between each of these concepts/subconcepts and a manner in which to assess them, in the form of tasks, conditions, and standards
- Tutoring information available for instructional actions, in the form of hints or adaptations.

The classification of information into this schema allows for a single configuration instance (Domain Knowledge File) to be mostly reused across simulators, for a single simulator to train different tasks according to its tutoring configuration, or to keep all of the other modules of GIFT stable while training a new task in a new domain.

In addition to creating a required method of representing abstract domain structure, domain content is supplemented with information reflecting its content and usage, called metadata and paradata. This information, like the three types of information above, can be abstractly defined for a variety of domains. One of the key features of GIFT is that it allows these features to be built organically; if authored content is available in a compatible manner, it can be seemlessly integrated into the course of instruction, if information (content, assessments, metadata, etc.) is not available, the system defaults to its best guess at appropriate material. The construction of training material in this fashion allows for adaptive capabilities to be built after an initial training system, and to be incrementally constructed.

5.1. Metadata and Paradata

The Engine for Management of Adaptive Pedagogy (EMAP) (Goldberg et al., 2012), the default instructional engine behind GIFT, is able to select among the domain-general content to which it has access. It selects this content based upon domain-general content traits and learner-general traits. As an example, a learner who has been identified as having "Low Motivation" can be served the content with the highest Interactive Multimedia Instruction (IMI) level available. A "High Motivation" learner in the same situation may be given material where the IMI is lower, but the coverage is greater, according to the individual learner's interest and need. The matching of these content traits and learner traits without specific information allows these actions to be performed in a number of disparate instructional contexts. The default instructional engine is based upon a great deal of research, but can be easily reconfigured to support experiments, while tagging individual items with content has additionally been simplified, shown in direct comparison at a glance in Figure 4.

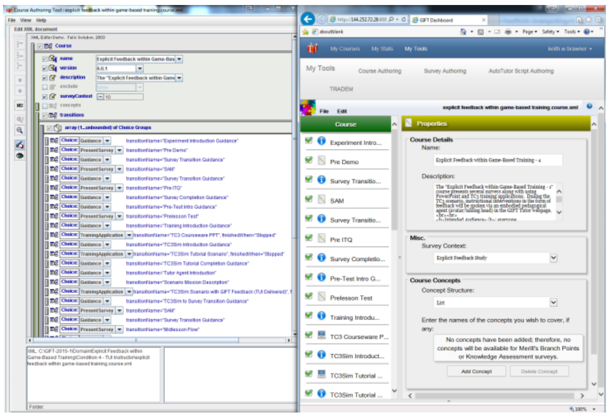

Figure 4: Example of authoring tool simplification

If there are two pieces of content, or instructional events, which have the same metadata descriptions, it raises the question of "which set should be given?". GIFT uses paradata, or usage data, to adjudicate the case for the recommendation of matching or identically described content. Currently this is implemented as a ".paradata" file located next to the content in question, but this serves as the placeholder for larger and more appropriate social media based rating systems, mentioned earlier, to adjudicate appropriateness of individual content selections (Boland et al., 2015).

5.2. Interoperability concerns

As part of the creation of an ontological categorization of domain-specific information, there is difficulty in maintaining the flexibility to the system to adjust to new domains of instruction while supporting both existing research projects and transition into systems of practice. The construction of models which are domain-general and compatible with GIFT is more difficult than the traditional academic approach, but offers different advantages. The research approach of cobbling together a system for the purpose of testing a theory is helpful in that it can quickly prove novel research ideas. The engineering approach of designing a widely applicable and standardized system allows for the use of proven research outside of its original laboratory. Given that ITS research has a long history of being useful, it is the position of the ARL that the time is right to attempt the engineering of a wide-scaled system for practical use. While the incorporation of content in a general-purpose system may be more difficult, it is possible for it to see broader applicability.

A typical training model for current military instruction involves training in multiple environments prior to putting the learned information into practice. As a concrete example, a student may be assigned reading on the operation of a vehicle, given an interactable model of its maintenance, trained in a simulated environment, trained in a practice environment, operate the vehicle in the field, and receive embedded training during downtime. Sharing data across such disparate systems, at a granularity where tasks can be accomplished, is a difficult problem which calls for interoperable standards. Examples of tasks are predictive modeling (will a student with X knowledge succeed at Y course), transferability (student with knowledge X can skip content Y), or effectiveness (student performing well on X performs well in the field). GIFT has chosen xAPI (Regan, 2013) as an emerging standard which can support the need for this type of actionable data and research question investigation. Other emerging standards such as the Human Performance Markup Language (HPML) (Stacy, Ayers, Freeman, and Haimson, 2006) are additionally under consideration for the representation of fine-grained performance data.

6. SUPPLEMENTATION OF CONTENT WITH TUTORING INFORMATION

Initial presentation of content is merely the first part of the tutoring process. A full tutoring process involves content such as hints, prompts, pumps, assessing questions, or topic sequencing. The current manner of generating this type of supplemental content is manual; after the initial training content has been developed, the author is asked to create this type of material. In the creation of an item such as a hint, the domain expert may create an assessing question for each key concept in a supply of training material, a hint for each question, and a series of hints of escalating granularity for concepts which are known to give students issues.

The creation of this supplementary tutoring information generally takes comparable time to the creation of the initial training material. As a byproduct of the time required to create supplementary tutoring information, its creation by training instructors is performed with some trepidation. GIFT allows the creation of training material in the absence of its tutoring information, but these are the types of information are where learning gains over textbook reading are found; without the tutoring information, it is simply a “page turner”.

There are projects involved with automating the tutoring supplemental content. As an example, it is possible, from a variety of texts to establish the order of instruction which is consistent among the domain (Robson, Ray, and Cai, 2013). Assessing questions can be automatically generated through question generation techniques which generate multiple choice questions and distracters (Olney, Graesser, and Person, 2012). Hints can be generated using a historical series of previous student actions, represented as a Markov Chain, to provide a ‘hint factory’ (Stamper, Barnes, Lehmann, and Croy, 2008). Generally, there is some evidence that the types of supplemental material which authors are reluctant to author can be performed automatically.

7. ARCHITECTURAL RESEARCH GOALS

7.1. A Single Point for Training

GIFT does not aim to be a single point for all data to be stored and indexed. However, the goal is to be able to ease integration with a variety of training environments for the purpose of capturing training outcomes and standardizing processes. A good architectural structure should allow for the easy import of existing training content, augmentation of its' resources, sharing of intelligent tutoring system resources, delivery of tutoring instruction, provision of grading information back to instructors, and tracking of long-term learning data. In support of these goals, GIFT has a series of web-based authoring tools, a manner of integration with existing simulators, the ability to share a completed tutoring system. Each of these could have more functionality, but are provided as bare-bones to a diverse set of training systems. The goal is to provide the tools integrate with training systems, and to be able to capture training information where possible. To this end, GIFT may work as an enhanced version of the Gooru Learning platform, which indexes instructional content for use in classroom settings (GooruLearning, 2014).

7.2. A Single Point for Users

To the end that GIFT may function as a single point for training content, it is the intention for it to be a single point for users to access other systems, with tutoring optionally applied as an overlay or integrated into the system directly. User needs are simplistic: to access training content, to store a history of their training, and to provide curation and recommendation for future courses. Previous efforts in this area (Mangold, Beauchat, Long, and Amburn, 2012) are being folded into the GIFT project in an effort to provide this single sign-on and tracking functionality for taking training, gaining access to new training, lodging social media objections, and other items. Future versions of GIFT will be distributed as virtual machines, for set up at individual schoolhouses, with interoperability with existing or external Learner Record Stores (LRS) (Regan, 2013).

7.3. Single Point for Analysis

Using a single system to create and take training allows for research on the creation and use of training. This includes many interesting authoring research questions such as "which types of instructional domains are most difficult to create training for?", "how can semi-automated tools improve to provide additional levels of automation?" and additional learner modeling research questions such as "which courses are the most critical for future leaders to do well in?" or "how long, on average, does it take before someone forgets critical aspects of their medical training?". Standardizing the data flow across disparate systems allows for the creation of analysis tools which can be applied to these systems. The introduction of powerful analysis tools to answer these research questions for disparate systems, at different types, at different granularity, for different users and groups of users is an architectural research goal. Cooperation with different teams in this area (Koedinger et al., 2015) will be a key point for reuse and success.

7.4. Automated background processes

As mentioned in section 6, automation can magnify individual impact. There are a number of opportunities in automation of learning systems. Some of these involve using AI processes to assist a course creator, such as the creation of course content and supplementary tutoring content. Some of these involve enhanced modeling of users for customized recommendations and assistance. Some of these involve the identification of poorly performing, or highly discussed, course content. Some of these involve items such as customized scenario generation to train automatically identified learner weaknesses. Having data in a single point allows for the reuse of these processes across domains of instruction and gives the benefits to the final users of the software.

7.5. Single Point of Integration

Lastly, the lessons learned from the earlier TAO ITS system have not been forgotten. GIFT serves as a platform which encapsulates the current state of the science in an existing system for experimentation and use which can be implemented as a traditional engineering "black box", and provides tools to do so. GIFT is able to readjust its assessment logic without reengineering, through relatively simple changes in configuration files by using existing tools. GIFT is frequently repurposed for new tasks on an existing simulation without the reinvention of the system itself. GIFT has an open architecture to facilitate long-term logistics cost of software, and is released publicly. All of these items allow for the ease of integration with other existing systems.

These integration goals are intended to allow for the proliferation of systems, by making their creation easier. They allow for the change of modules, or introduction of new models within modules, without re-creation of the system. They additionally allow for the ease of data collection and analysis.

8. CONCLUSIONS

Over fifty years of AI research has failed to produce generalized standards for authoring ITSs, automation of their instructional processes, or evaluating their effect. GIFT arose as an open-source, modular architecture to support more standardized processes in ITSs to allow interoperability of components and to reduce the skill/time required to author ITSs. This paper describes the research and development of GIFT capabilities (existing and future needs) and outlines challenge areas in adaptive training research in authoring, automated instruction, domain modeling, and supporting architecture. GIFT serves as community-based project that needs a large group of practitioners to prosper, grow, and drive official standardization. It is essential moving forward that GIFT is architected to support a wide-variety of domains (e.g., cognitive, affective, psychomotor, and social/collaborative) to validate its design principles and to demonstrate its authoring and evaluation tools and methods. To this end, we reach out to the global community to apply GIFT freely and provide feedback on its performance. The development of ITS standards will result in lower development time/cost, and higher levels of reuse across all of the participants.

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OPTICAL ENGINEERING SIMULATOR DEVELOPMENT FOR EFFICIENT DESIGN OF MILES GEAR

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ABSTRACT
Most of live military training systems are based on the MILES gear. In order to simulate the real engagements, it simulates a gunfire using a laser beam, and death by being shot is judged by sensors, which are attached on the trainer's body. Therefore, one of the important design consideration is to choose proper specifications of MILES gears to embrace the properties of real firearm. To decide the specification of MILES gear, the designer should decide several things. The problem is that conducting this with real experiments needs a lot of time and cost because of too many combinations of specifications. This paper suggests an optical engineering simulator to compute an efficient design of MILES gear. The simulator is based on the domain knowledge of the laser beam and the sensors to acquire high fidelity results, so that the designer of MILES gear may find the proper specifications easier.

Keywords: MILES gear, Modeling and Simulation, Simulation Based Acquisition

1. INTRODUCTION

Multiple Integrated Laser Engagement System (MILES) is widely used in about 32 national militaries to conduct live military training.(Wikipedia 2015) In order to give immersive experience to the trainees, MILES gear simulates real engagements with a laser beam and multiple laser sensors. The laser beam describes a bullet with a beam width, and it is emitted from the transmitter mounted on a real firearm. The diameter of beam region is decided by the beam width, and all the sensors are activated in the beam region. The sensor attached on a body detects the laser beam and decides whether the bullet hits the body or not (Jones, Huang, and Bian 2008).

To increase the effectiveness of training, several properties of MILES gear should be the identical as that of a real firearm. Among the properties, a hit rate is one of the important property. The hit rate means chance to hit (or detected by sensors) a target when you fire an aimed shot to it. In case of a real firearm, the hit rate is close to 100 percent, because all area of trainee's body is effective area for real bullets. However, it is hard that the hit rate of MILES gear achieves 100 percent because of the beam width, the limited number of sensors, and restricted location of attaching sensors. If the designer wants to make the hit rate of MILES gear to be 100 percent, the beam width should be converge to zero without decreasing the range of the beam. On the other hand, the number of sensors should be infinite to cover entire area of the trainee's body.

Reducing the beam width without decreasing its range can be achieved by increasing the initial energy to generate the beam, and, unfortunately, it is dangerous to the trainees. Whereas, the large number of sensors may restrict the movement of the trainees. If the designer decides to attach the large number of sensors to the trainees, the sensors should be small enough so that the trainee can attend training without any restriction. However, it leads to a budget problem. Therefore, the designer of the MILES gear should comprise aforementioned considerations to choose proper specifications of MILES gear to simulate real battle using the MILES gear.

Among several design considerations of the MILES gear, the important design considerations of the MILES gear are 1) the beam width; 2) the number of sensors; and 3) the location of the sensors. The designer should consider the combinations of the design considerations. However, combinations of specifications are too many so that the designer cannot test each combination of the consideration in real environment. To tackle the problem, this paper proposes an optical engineering simulator to decide proper specification of the MILES gear. It is based on the domain knowledge of a laser beam and sensors and it models physical characteristics of the laser beam and the sensors to get high fidelity results. As a result, simulator helps decision makers and designers to find proper specifications of MILES gears.

This paper is organized as follows. Section 2 illustrates the differences and the similarities between real firearm and the optical engineering models of the proposed simulator such as the hit rate. In Section 3, we introduce mathematical definitions of the component models for MILES gear, and in Section 4, we proposes the optical engineering simulator using these models. Several simulation results are showed in Section 5 and finally, we conclude in Section 6.

2. COMPARASION WITH REAL FIREARM

As we mentioned in the Section 1, the hit rate of MILES gear should be the identical as that of a real firearm to increase an effectiveness of training. When the number of sensors is limited, increasing the beam width makes the hit rate similar to a real firearm. However, MILES gear has the additional hit rate called a near-hit rate caused by the beam width.

To define the near-hit rate, Figure 1 classifies the beam according to relationships about beam, sensors, and target. The beam is classified into 3 groups according to relationship between beam and target: *not-hit*, *hit*, *near-hit*. The *not-hit* means the beam does not overlap with the target. In case of overlapping, the beam is classified into 2 groups according to the location of center of beam. If the center is on the target, the beam is classified as *hit*. Otherwise, it is classified as *near-hit*.

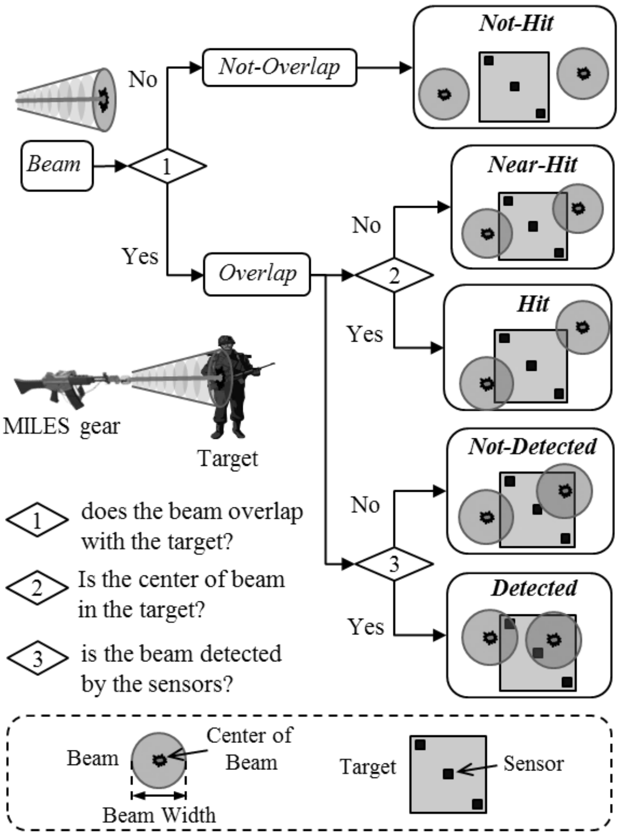


Figure 1: Classification of Beam

For the *hit* and *near-hit* beams, they are classified into 2 groups according to relationship between beam and sensors: *detected*, and *not-detected*. If sensors can detect the beam, it is categorized as *detected*. Otherwise, it is categorized as *not-detected*. The hit rate and near-hit rate is the rate of the *detected* beams among the *hit* beams and the *near-hit* beams. Using these classification, the hit rate(P_H) and near-hit rate(P_N) are defined as below.

$$P_H = \frac{n(Hit \cap Detected)}{n(Hit)} \tag{1}$$

$$P_N = \frac{n(Near\text{-}Hit \cap Detected)}{n(Near\text{-}Hit)} \tag{2}$$

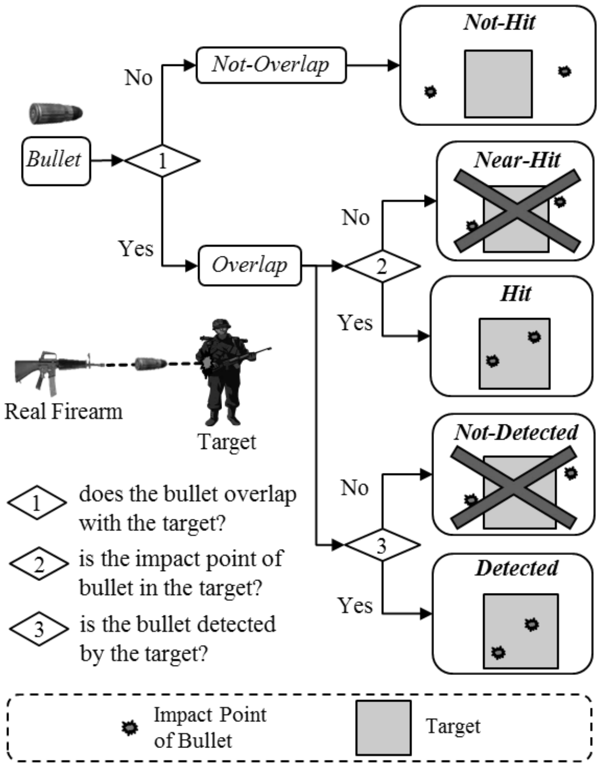


Figure 2: Classification of Bullet

Comparing MILES gear with a real firearm, a bullet is not classified as *near-hit* because of the size of bullet. The size of bullet is almost 0 compared to the beam width. (i.e. center of beam is considered as the impact point of bullet.) Also, since all of the parts of the target can detect the bullet, *not-detected* cannot be occurred.(see Figure 2) Therefore, the hit rate of a real fire arm is 100 percent without any side-effects such as wind, aiming error, gravity, and so on. Also, the near-hit rate is 0 percent because of no bullet classified as *near-hit*. However, the hit rate of MILES gear is below 100 percent and the near-hit rate of it is over 0 percent because of the beam width and the limited number of sensors. Figure 3 shows this using a Venn diagram.

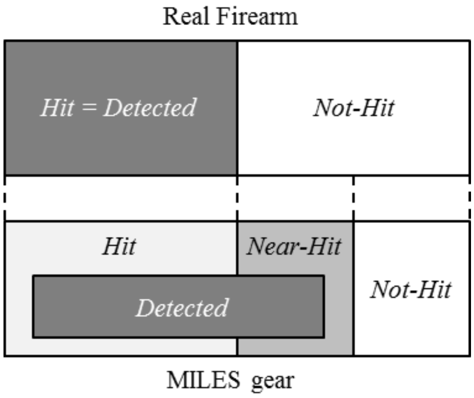


Figure 3: Comparison with Real Firearm

To design MILES gear similar to a real firearm, the hit rate should go up to 100 percent and the near-hit rate should go down 0 percent. To achieve the hit rate as 100 percent, increasing the beam width or the number of sensors is a simple way. However, this leads to rising the near-hit rate. On the contrary to this, decreasing the beam width or the number of sensors to achieve the near-hit as 0 percent, lowers the hit rate. Ideally, achieving the hit rate and near-hit rate to 100 and 0 percent are accomplished by reducing the beam width to almost 0 and increasing the number of sensors on the target infinitely. However, it is impossible because of the several reasons as mentioned in Section 1. Therefore, when you designs MILES gear, chooses proper specifications to maximize the hit rate and minimize the near-hit rate. The following sections will explain the optical engineering simulator for doing this easily.

3. COMPONENTS MODELING

This section will explain about 3 component models of MILES gear such as laser beam, sensor, and target for calculating the hit rate and near-hit rate.

3.1. Laser Beam Model

3.1.1. General Gaussian Beam Model

Gaussian Beam Model is a general model for describing a laser beam.(Quimby 2006) Mathematical representation of the model and parameter descriptions are below.(see Figure 4)

$$I(r,z) = I_0\left(\frac{w_0}{w(z)}\right)^2 \exp\left(-\frac{2r^2}{w^2(z)}\right) \qquad (3)$$

$$w(z) = w_0\sqrt{1+(z/z_R)^2} \cong \sqrt{w_0^2+\theta_0^2 z^2} \qquad (4)$$

- $I(r,z)$[W/m^2]: intensity of beam
- z[m]: distance from the initial point of beam to the center of beam
- r[m]: radial distance from the center of beam
- θ_0[rad]: divergence angle of beam($\cong w_0/z_R$)
- w_0[m]: waist of beam
- z_R[m]: Rayleigh range

The intensity of beam$\left(I(r,z)\right)$ following Gaussian is diffused as the distance(z) increases. The points apart from the center of beam as the same radial distance(r) have equal intensity and that makes cross section of beam circular. The center of beam means an intersection point between the center axis of beam and a plane. (The plane is one of the faces that construct a target.) Using the representation, we define the beam width (R) mathematically. The beam width is a diameter of area(circle) where the intensity of beam is above the intensity threshold of sensor(D_L). In other words, sensors which are in the area can be activated by the beam. Mathematical representation of the beam width is below.

$$R(z) = 2\sqrt{-\frac{w^2(z)}{2}ln\left(\frac{D_L}{I(0,z)}\right)} \qquad (5)$$

- D_L[W/m^2]: intensity threshold of sensor

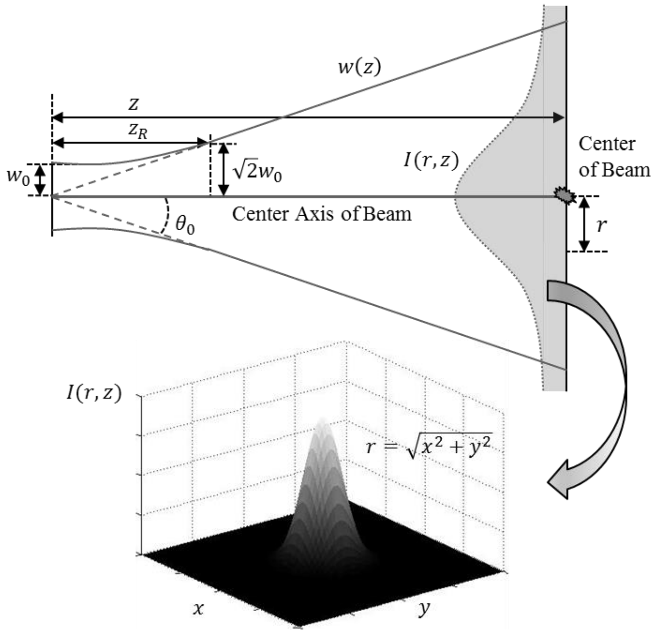


Figure 4: Gaussian Beam Model Parameters & 3D Plot of Intensity$\left(I(r,z)\right)$

The beam width is decided by the distance and the intensity threshold. Figure 5 shows the beam width according to the distance. It increases as the distance increases until at a certain point, and decreases after the point. If the distance is over the maximum distance(z_{max}), the beam width becomes 0. Therefore, when designing MILES gear to simulate a real firearm, deciding the maximum distance with consideration for the maximum range of it is important.

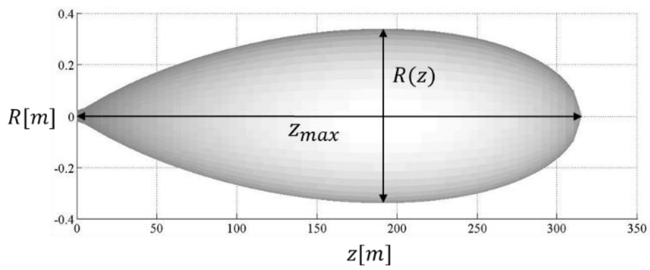


Figure 5: Beam Width(R) According to Distance(z)

3.1.2. Extended Gaussian Beam Model

In real cases, the beam does not come at a right angle to a target (i.e. the incidence angle(θ_I) is 0°). However, the general model does not deal an incidence angle. To increase fidelity of the simulator, this paper proposes an Extended Gaussian Beam Model including the incidence angle. To simple calculation and expression, the paper puts an assumption that all of the axes constructing the beam have the same incidence angle. (i.e. all of the axes are parallel each other.) The extended mathematical representation of the model and additional parameter descriptions are below.

$$I(x, y, z, \theta_I) = I_0 \left(\frac{w_0}{w(z)}\right)^2 \cos\theta_I \exp\left(-\frac{2x^2 + 2y^2 \cos^2\theta_I}{w^2(z)}\right) \quad (6)$$

- θ_I[rad]: incidence angle
- (x, y): coordinate from the center of beam

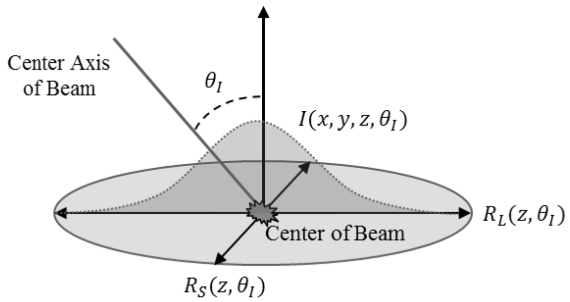


Figure 6: Extended Gaussian Beam Model

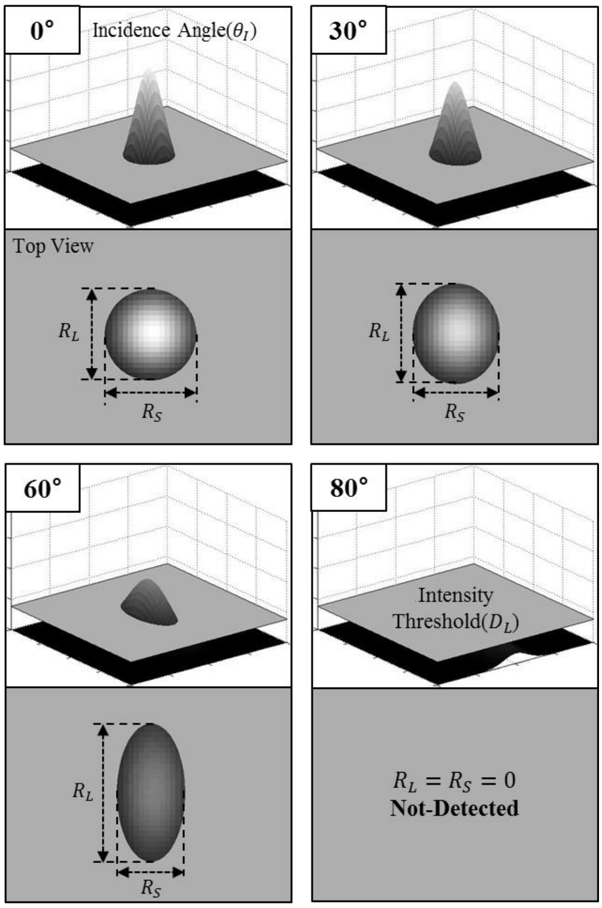


Figure 7: Change of Beam Widths(R_L, R_S) According to Incidence Angel(θ_I)

Because the intensity is diffused to the incidence direction, the intensity of points apart from the center of beam as the same radial distance are not equal. That means the cross section of the beam transforms from a circle to an ellipse. The radial distance is replaced by the coordinate from the center of beam and the beam width is also divided into 2 different parts: long beam width (R_L) and short beam width (R_S) .(see Figure 6) They are respectively twice the major axis and the minor axis of the ellipse. Mathematical representation of these are below.

$$R_L(z, \theta_I) = 2\sqrt{-\frac{w^2(z)}{2\cos^2\theta_I} ln\left(\frac{D_L}{I(0, z)\cos\theta_I}\right)} \quad (7)$$

$$R_S(z, \theta_I) = 2\sqrt{-\frac{w^2(z)}{2} ln\left(\frac{D_L}{I(0, z)\cos\theta_I}\right)} \quad (8)$$

Based on the representation (7) and (8), we define the limit incidence angle(θ_L) that means the long width and the short width remain 0 after the angle. If the incidence angle is more than the limited angle, the intensity is diffused so widely that no points are over the intensity threshold of sensor.(see Figure 7) The limit incidence angle decreases as the distance increases. Therefore, when designing a sensor, take care of the limited angle and decide the parameters of the sensor. Mathematical representation of the limited angle is below.

$$\theta_L(z) = \cos^{-1}\left(\frac{D_L}{I_0(w_0/w(z))^2}\right) \quad (9)$$

In the simulator, a beam consists of a coordinate which is on a virtual sphere, and a vector that indicate direction of the beam. Size of the vector is the same as the distance of beam. The simulator generates and classifies the beam using the Extended Gaussian Beam Model. Section 4 will explain this in detail.

3.2. Sensor Model

A sensor model is quite simple. In the simulator, it is abstracted to a point because its size is very small as compared to the beam width. The sensor model has 2 parameters: intensity threshold(D_L), angle threshold(θ_D). As mentioned previously, the intensity threshold of sensor is used to define the beam width. The angle threshold of sensor, different with the limited incidence angle (θ_L) mentioned in the last section, is a limit incidence angle in terms of sensor. That means the sensor can detect the beam whose incidence angle is under the minimum between the limited incidence angle(θ_L) and angle threshold(θ_D). Therefore, the sensor detects the beam whose intensity on the sensor is over the intensity threshold and incidence angle is under the angle threshold. Simply put, the sensor where is in the ellipse of the beam, is activated.

In the simulator, a sensor consists of a location coordinate on s target and a vector that indicates direction of the sensor. The vector is equal to the normal vector of the face where the sensor is on. Using the mentioned sensor model, the simulator decides whether the sensor detects a beam or not.

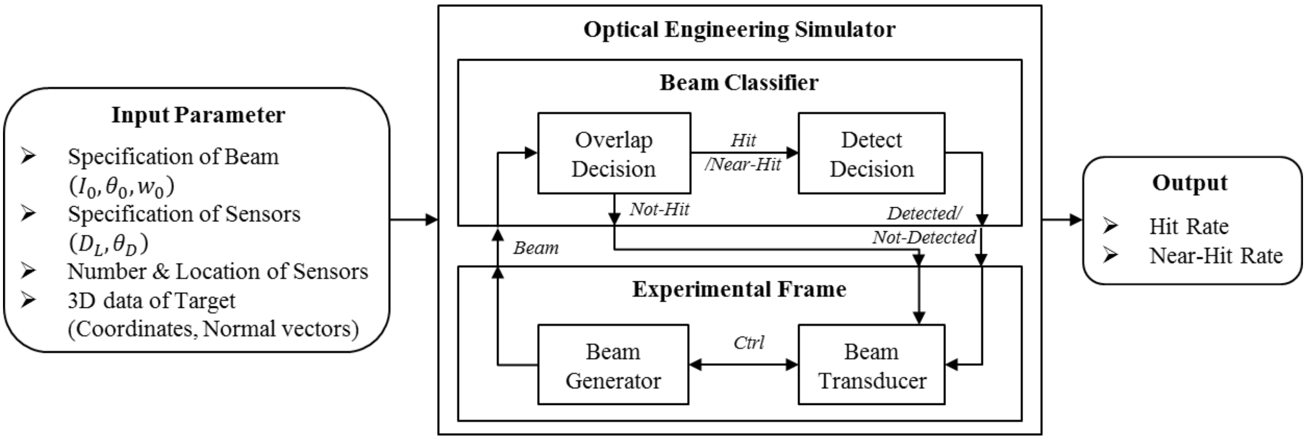


Figure 8: Structure of Optical Engineering Simulator

3.3. Target Model

A target model is a 3D mesh model. It consists of coordinates of the faces constructing the target and normal vectors whose direction is outside of the faces. The sensors can be on the faces. The simulator calculates the center of beam, the incidence angle and the beam widths about all of the faces to check whether the beam overlaps with the faces. The following section will explain this in detail.

4. OPTICAL ENGINEERING SIMULATOR

The optical engineering simulator calculates the hit rate and near-hit rate of MILES gear in given input parameters. The parameters are about the beam model, the sensor model and the target model mentioned in the previous section. Figure 8 shows the structure of the optical engineering simulator. The simulator consists of 2 main models which are the Experimental Frame and the Beam Classifier.

4.1.1. Experimental Frame

The experimental frame based on Zeigler, Praehofer, and Kim (2000) generates beams and analysis them. It has 2 sub models which are Beam Generator and Beam Transducer. The beam generator generates beams to the beam classifier and the beam transducer calculates the rates from the classification result of the classifier.

4.1.2. Beam Generator

Because the number of *hit* and *near-hit* beams of a target is infinite, the beam generator generates beams using the Monte-Carlo simulation method.(Mooney 1997) In other words, the generator chooses the finite number of beams from a set of all *hit* and *near-hit* beams, and generates them to calculate the hit and the near-hit rate. To get the accurate rates, the set should include all of *hit* and *near-hit* beams. For this, the paper proposed a concept of virtual sphere.

The virtual sphere surrounds a target which is on the center of the sphere. If the size of the virtual sphere is enough large, all of the *hit* and *near-hit* beams of the target have the center of beam on the inside of the sphere. Inversely, to simulate all of these beams the generator generates beams whose center of beam are on the inside of the sphere. Therefore, the generator generates a beam using 4 random parameters: ①center of beam, ②theta of beam(θ_{Beam}), ③phi of beam(ϕ_{Beam}), ④distance of beam(z_{Beam}).(see Figure 9) The generated vector of the beam(V_{Beam}) is below. (The subscript '$_{Beam}$' is omitted.)

$$V_{Beam} = -(z \cdot sin\theta cos\phi, z \cdot sin\theta sin\phi, zcos\theta) \qquad (10)$$

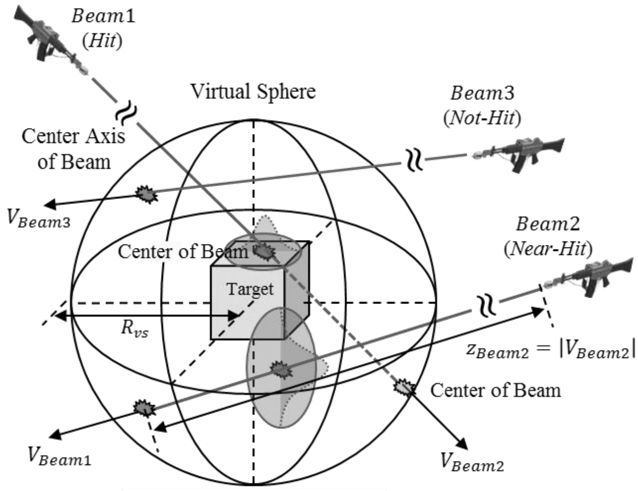


Figure 9: Virtual Sphere

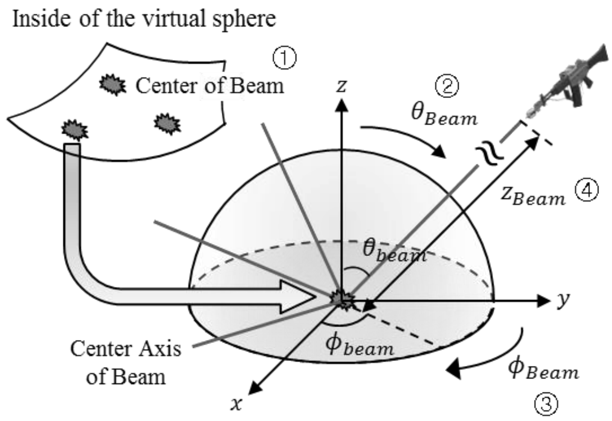


Figure 10: Generating Parameters of Beam

As mentioned previously, the radius of virtual sphere should be enough long to include all of the *hit* and *near-hit* beams of the target. If the radius is too long, the sphere include excessive *not-hit* beam additionally. That makes the simulator generate more beams to get the results and reduces the performance of the simulator. Otherwise, if the radius is too small, the sphere cannot include all of the *hit* and *near-hit* beams. That makes the simulator draw out wrong results. Therefore, the appropriate radius is the minimum value among radiuses including these beams. The representation of appropriate radius is below. $Distance$ means a distance from the center of the target (usually $(0,0,0)$) to a point on the target.

$$R_{vs} = \max(Distance) + \max\big(R_L(z, \theta_I)\big) \tag{11}$$

4.1.3. Beam Transducer

The beam transducer collects classification result from the beam classifier and calculates the hit rate and near-hit rate using the equations (1) and (2). Also using *Ctrl*, it controls the generator such as stop and go.

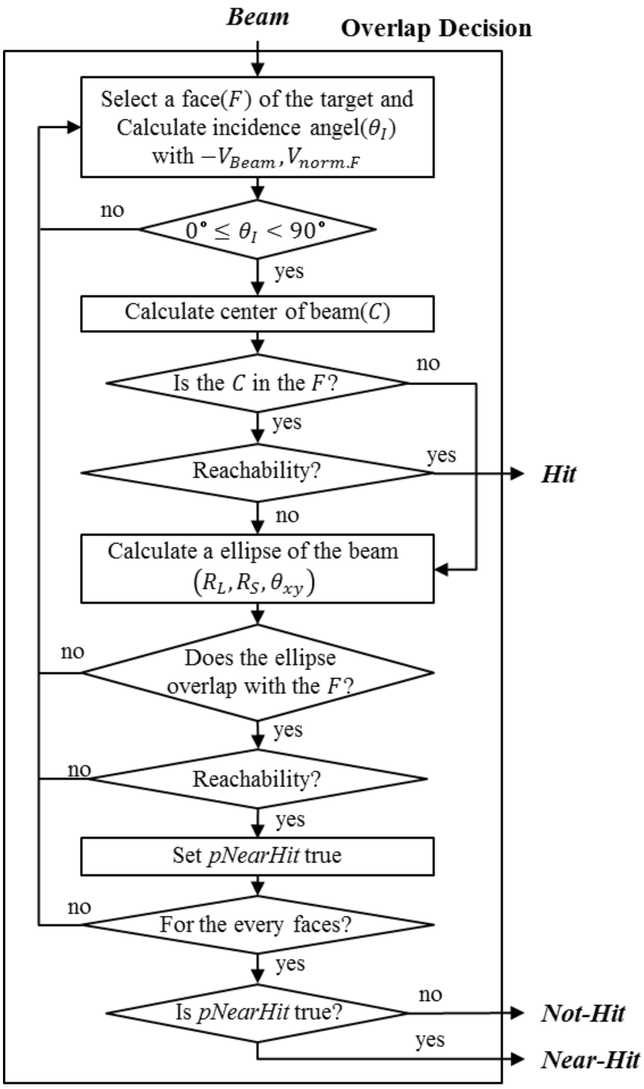


Figure 11: Algorithm of Overlap Decision

4.2. Beam Classifier

The beam classifier categorizes a beam according to the mentioned classification.(see Figure 1) It has 2 sub models witch are Overlap Decision and Detect Decision. The overlap decision decides whether a beam overlaps with a target and classifies the beam into 3 groups: *Not-Hit*, *Hit* and *Near-Hit*. For the beam classified as Hit or *Near-Hit*, the detection decision decides whether the beam is detected by sensors on a target and classifies the beam into 2 groups: *Detected* and *Not-Detected*.

4.2.1. Overlap Decision

The overlap decision is an algorithm model to classify a beam into 3 groups: *Not-Hit*, *Hit* and *Near-Hit*. Figure 11 shows the algorithm of the model and Figure 12 shows graphical representation of the algorithm. When a beam as an input enters to the overlap decision, it chooses one of the faces of a target and calculates an incidence angle between vector of the beam and normal vector of the face. If the incidence angle is between 0° and 90°, the beam can arrive at the face. Then it calculates the center of the beam which means the intersection point between the center axis of beam and the plane including the face. If the center of beam is in the face, then it checks reachability of the beam. The reachability means the beam can reach at the face without any interruption of the other faces. When the beam has reachability, the overlap decision categorizes the beam as *hit* and makes output.

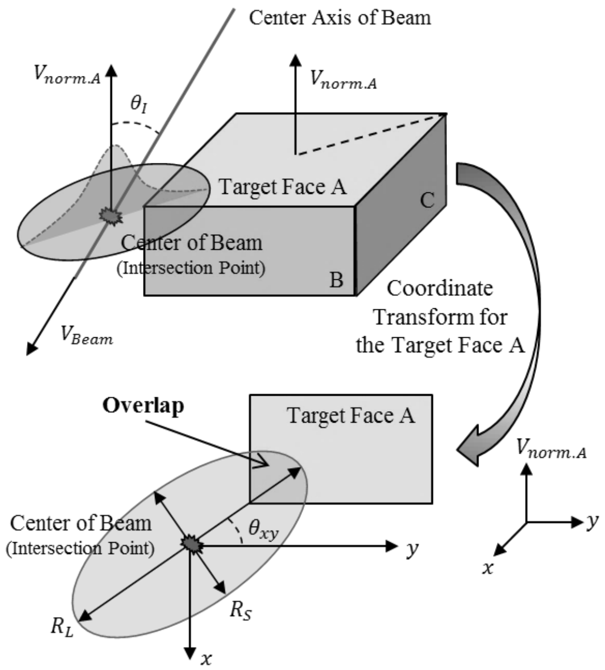


Figure 12: Graphical Representation of Overlap Decision

Otherwise, it calculates the ellipse of the beam (R_L, R_S, θ_{xy}) and decides whether the ellipse overlaps with the face. In case of overlapping, the overlap decision checks reachability of the beam. When the beam has reachability, the overlap decision sets *pNearHit* true. Because the beam can be classified into *hit* for the other faces, it cannot classify the beam into *near-hit* before checking all of the faces. Therefore, if the beam does not classified into *hit* until checking all of the faces and *pNearHit* is true, then the overlap decision classifies the beam into *near-hit* beam and makes output. Otherwise, if *pNearHit* is false, then it classifies the beam into *not-hit* and makes output.

4.2.2. Detect Decision

The detect decision is also an algorithm model to decide whether the *hit* or *near-hit* beam is detected by sensors. Figure 13 shows the algorithm of the model. The detect decision is similar to the overlap decision but more simple. When a *hit* or *near-hit* beam as an input enters to the detect decision, it chooses one of the sensors on a target and calculates an incidence angle between vector of the beam and vector of the sensor. The vector of sensor is the same as the vector of the face where the sensor is on. If the incidence angle is between 0° and the angle threshold(θ_D), it can arrive at the sensor and activate that with the intensity over the intensity threshold(D_L).

To check whether the intensity is over the threshold, the detect decision calculates the coordinate of the sensor (x, y) and the intensity $\left(I(x, y, z, \theta_I)\right)$ on that. When the intensity is over the threshold, it checks reachability of the beam to the sensor. In case the beam has reachability, the detect decision classifies the beam as *detected* and makes output. Otherwise, it chooses another sensor and checks that sensor again using the algorithm. If all of the sensors on a target does not detect the beam, the beam is classified into *not-detected*.

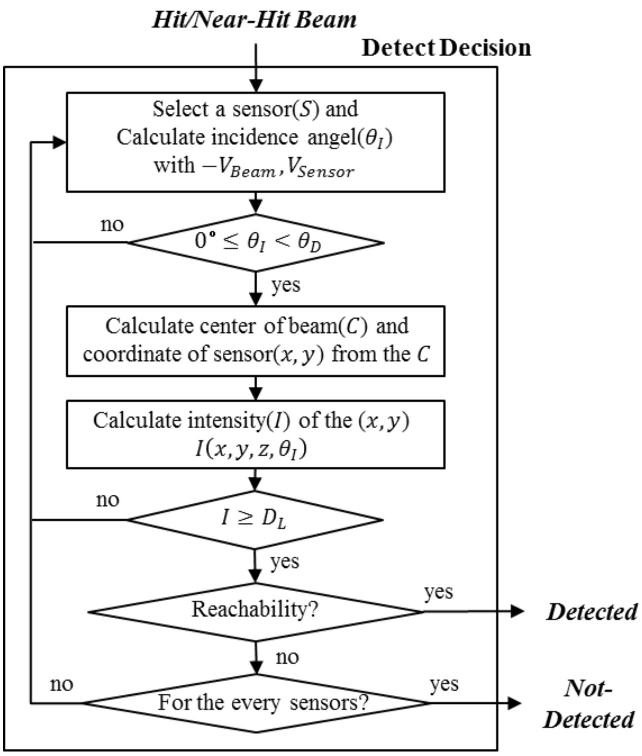


Figure 13: Algorithm of Detect Decision

5. SIMULATION RESULT

This Section shows how much effective the simulator is to design MILES gear. Using the simulator, it is easy to calculating the hit rate and near-hit rate for various input parameters without real experiments. Also, designers can get some useful insights of MILES gear from the results. Figure 14 presents a simple result of the simulator which is the hit rate and near-hit rate according to the distance of beam(z). The parameters of beam and the intensity threshold of sensor are set to achieve the beam width 60cm at the distance 250m and the maximum distance 350m.(the beam simulates K-1 rifle of ROK army) The angle threshold of sensor is set to 90°. The target is an infantry who has 6 sensor modules: 2 modules are on the head, another 2 modules are on the front body and the rest is on the rear body.(see Figure 14)

Meanwhile, the sensor module is a kind of cubic-shaped module which has 2 sensors in each faces except the attaching face. The module can detect more beams than a single sensor because it is virtually unaffected by the angle threshold (θ_D) and the limited incidence angle(θ_L). For example, the single sensor cannot detect a beam whose incidence angle is 80°, because of the limited incidence angle. However, the module can detect the beam because incidence angle between the beam and the sensors on the side face of the module is just 10°. Therefore the beam can be detected by the module. (Actually the sensors on the side face of the module detect the beam.)

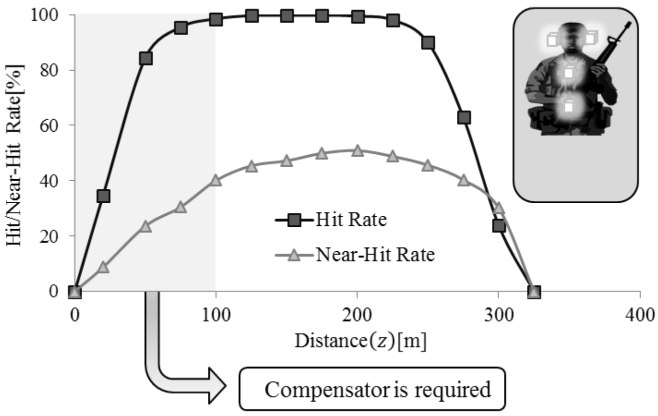
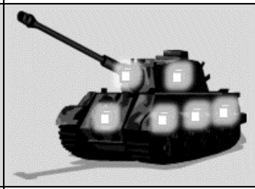


Figure 14: Hit/Near-Hit Rate According to Distance of Beam

The hit rate and near-hit rate increase as the distance increases until at 100m, then the hit rate keeps 100 percent and the near-hit rate rises slowly. After about 200m, they decrease rapidly and go to 0 percent at roughly 330m which is approximation of the maximum distance 350m. The shape of the graph is similar to that of the beam width, because the hit rate and near-hit rate are greatly affected by the beam width.(see Figure 5) This gives a useful insight of MILES gear which is a requirement of compensator. In case of a real firearm, the hit rate at close range is 100 percent even though considering side-effects such as wind, aiming error, and so on. However, because the beam width at close range is too small to activate sensors, the hit rate is low at the close range. Therefore, an additional beam is required as the compensator to increase the hit rate at the close range.

Table 1: Hit/Near-Hit Rate According to Target Model

Target Model	**Infantry**	**Tank(K-1)**
Loc. of Sensors		
# of Sensors	6 modules	12 modules
Hit Rate	89.7% at 250m	50.3% at 250m
Near-Hit Rate	46.1% at 250m	16.6% at 250m

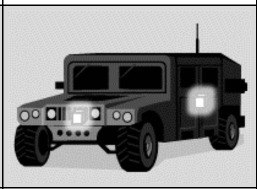
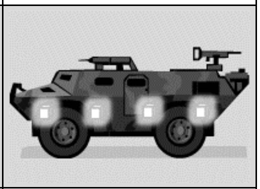
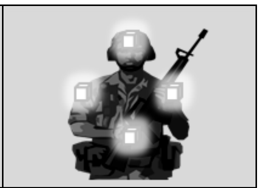
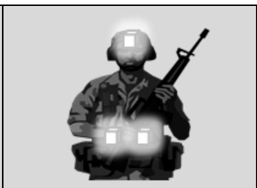
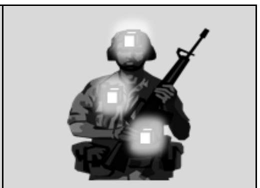
Target Model	**Vehicle(K-111)**	**Vehicle2(K200)**
Loc. of Sensors		
# of Sensors	4 modules	6 modules
Hit Rate	62.0% at 250m	46.1% at 250m
Near-Hit Rate	20.1% at 250m	13.1% at 250m

Table 2: Hit/Near-Hit Rate According to Location of Sensors

Loc. of Sensors		
# of Sensors	6 modules	6 modules
Hit Rate	89.7% at 250m	99.2% at 250m
Near-Hit Rate	46.1% at 250m	52.4% at 250m
Loc. of Sensors		
# of Sensors	6 modules	6 modules
Hit Rate	84.0% at 250m	89.3% at 250m
Near-Hit Rate	46.6% at 250m	47.9% at 250m

Besides getting some insights, the simulator can give results for various input parameters. Table 1 shows that the hit rate and near-hit rate according to various target models. Except the case of infantry, the parameters of beam and the intensity threshold of sensor are set to achieve the beam width 150cm at the distance 250m and the maximum distance 350m.(the beam simulates M72LAW antitank weapon of ROK army) The angle threshold of sensor is set to 60°. The parameters of infantry cases are the same as Figure 14's one. Each target models have several sensor modules and the location of modules is in Table 1. All of the hit rates and the near-hit rates of targets are calculated at the distance 250m.

Table 2 shows that the hit rate and near-hit rate according to the location of sensors. The parameters of beam and sensor are the same as Figure 14's one. Each infantry targets have 6 modules attached at different locations. All of the hit rates and the near-hit rates of targets are calculated at the distance 250m.

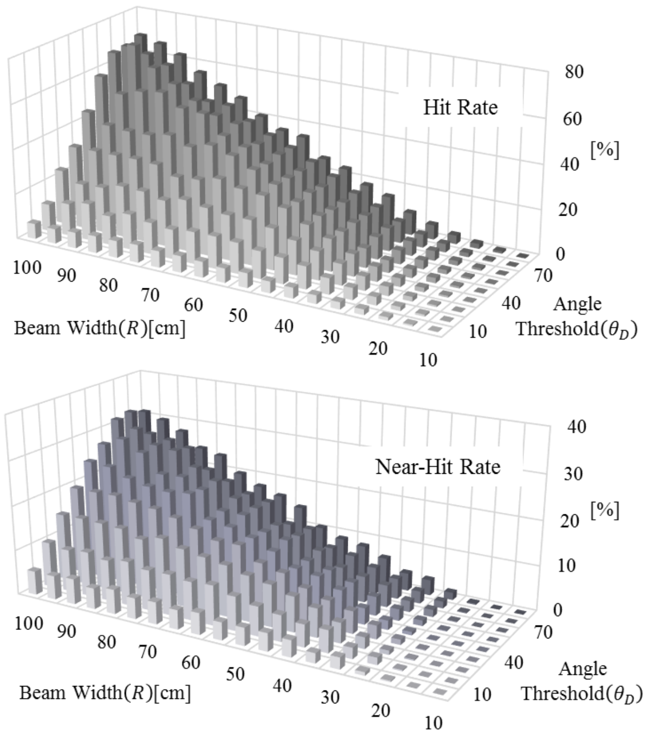


Figure 15: Hit/Near-Hit Rate According to Beam Width and Angle Threshold

Figure 15 shows that the hit rate and near-hit rate according to the beam width and the angle threshold. The number and location of sensors are the same as Figure 14's one except that the modules are replaced with single sensors. Because of this, the hit rate is lower than Figure 14's one in the same condition. Among the parameters of beam model, the initial intensity of beam(I_0) is changed to achieve the beam width and the others are invariable. The beam width and the angle threshold are increased from 10cm to 100cm and from 0° to 90° respectively. All of the hit rates and near-hit rates of targets are calculated at the distance 250m. Figure 15 demonstrates that the hit rate and near-hit rate are increased as these parameters are increased.

Like all of these results, the simulator can give the hit rate and near-hit rate for various input parameters, and sometimes it can give useful insights of MILES gear. Designers can find the proper specifications of MILES gear efficiently using the simulator, and that reduces the time and cost for real experiments. In addition, if some constraints are given, designers can find the optimal combination of parameters using the simulator and optimization methods: simulated annealing, genetic algorithm, and so on.(Gosavi 2014)

6. CONCLUSION

This paper proposes the Optical Engineering Simulator for an efficient design of MILES gear. The simulator calculates the hit rate and near-hit rate in given parameters of component models: beam model, sensor model, and target model. The beam model and sensor model calculates the beam width based on the Extended Gaussian Beam Model which includes the incidence angle. The target model is a 3D mesh model and has the sensor models on the faces of it. Using these component models, the simulator makes the output through the Experimental Frame and Beam Classifier. The experimental frame generates beams to the classifier and analyzes the classification results. The beam classifier is an algorithm model for categorizing the beam. The simulator reduces the time and cost for real experiments and make it easier to choose proper specifications of MILES gear.

There are 2 future works of the simulator. The first work is to expand the simulator, to deal with a moving target. In an actual training process, all of the soldiers are moving continually. However, the current simulator can deal with only a stalled target. The results from this simulator is difficult to apply it to an actual training process. The works will allow that the simulator is used more practically. The second works is to add MILES Communication Code(MCC).(U.S. Army's PEO-STRI 2011) MCC is a kind of signal that is transmitted by a laser beam, and used to assess damage of a target. Considering the code will increase the capability of the simulator.

ACKNOWLEDGMENTS

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A NOVEL APPROACH FOR MODELING COMPLEX DEEP FUTURES

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ABSTRACT
Many large-scale, complex systems consist of interactions between humans, human-made systems and the environment. The approach developed in this paper is to partition the problem space into two fundamental layers and identify, parameterize and model the main dimensions of each layer and interactions across and in between layers. One layer is the key actors or major organization or human decision makers who influence the state of the world. The other layer includes the domains or fields of knowledge relevant to the problem being addressed. These domains include elements such as the physical earth and its atmosphere, world demography, world economy, level of globalization, and politics. Key parameters for each of the actor types and domains will be extracted and assessed using existing data sources. Novel systems, uncertainty modeling and analysis techniques are combined with advanced computational technologies to determine a spectrum of likely future system states and conduct if-then scenario analyses.

Keywords: Bayesian Belief Networks, deep futures, deep learning, decision support system

1. INTRODUCTION

Senior military and civilian leaders must be enabled to anticipate global trends that may lead to crisis and conflict out to and beyond twenty-five years (so called Deep Futures). Global drivers of change are rapidly evolving and the timelines to respond are increasingly compressed. Proactive response to crisis is even better, effective action before crises manifest is essential to managing change and mitigating or minimizing potential conflict.

There is a rich literature reporting attempts to address the Deep Futures problem, however most of this work addresses pieces of the overall problem. The comprehensive end-to-end world model we feel is necessary for this problem has not yet been built. Our modeling experience is that end-to-end system models are required especially in this case where there are evolving interactions between domains of knowledge, world trends, global actors and their decision mechanisms.

Accomplishing this objective requires creation of analytic and forecasting tools able to help identify and evaluate global drivers of change, their interactions and potential outcomes. This paper articulates the vision, methodology and approach to developing a conceptual model and a solution toolkit. The toolkit is named "Themis".

The technical underpinning of the Themis concept is based on the belief that the risks, mitigations to those risks and opportunities for the actors around the world can be computed sufficiently to add actionable value to users. Themis will be developed as a framework and corresponding methodology which draws from basic mathematical modeling techniques and disciplines and enables orchestration of existing limited scope models into a global model via Themis ontology.

Subject Matter Experts (SME) will remain as the key source of input for developing the conceptual model as well as scenario-specific modifications to the concept. However, Themis will mitigate SME shortcomings by augmenting their knowledge by: (1) actual data feeds that are emerging from internet Big Data and sensor technology breakthroughs; (2) adaptive system technology with SMEs in the loop and (3) high performance computing technology.

It is critical to recognize that there are multiple views (concepts, theories and hypotheses) of how a situation in the world, nation, military, climate, economy, etc. unfolds. Themis will allow simulations to be run with different concepts, theories and hypotheses in order to understand and compare potential future landscapes. In order to provide this information, will include an analysis module, a data repository, a user interface and a scenario generator. The top-level product produced for users of Themis will be an "intervention index" computed from Themis' global assessment of the world situation at a given point in time that can be used as tripwires to trigger in depth analysis and mitigation.

This paper describes development of a Themis conceptual model including how the process must differ from some of the standard ways such models have been attempted in the past. A Themis preliminary concept of operation (CONOPS) is described that leverages Caltech's Jet Propulsion Laboratory's (JPL) Team X approaches to modeling, building and testing highly innovative, one-of-a-kind reliable complex systems. This approach is suitable to Deep Futures modeling which requires coordinating knowledge from a wide variety of global sources including SME's, users, real time and historical data feeds.

2. APPROACH

Themis intends to merge expertise and experience in developing kinetic and non-kinetic effects models for the US Army, complex systems modeling and design of innovative space systems and Team X methodology (Meshket, 2006) to develop an evolving comprehensive model of the world that provides users increasingly better responses to key questions. For example: What is the spectrum of driving world trends? What are the first and second order effects of actors' actions? What are the opportunities for specific actor interests? What are the opportunities for an actor's adversaries? to mention a few.

2.1. Standard Approaches

In developing the Themis concept current literature on emerging techniques and tools was reviewed. In particular, Waltz (Waltz, 2010) has a good comprehensive treatment of the methodologies, techniques and tools that have emerged due to the fact that "International interventions require unconventional approaches to modeling and analysis". Waltz further points out the reasons why conventional techniques are inadequate: (1) "number and diversity of the participants" and (2) "the effects space spans multiple domains" where there is "a lack of understanding of networked cause-and-effect relationships".

2.2. Subject Matter Experts (SME)

The scope of the kind of SMEs needed is greatly increased by Themis. Since Themis must model out 25 or more years, the world must be considered as a system so world SMEs are needed as well as the classical regional and topical experts. World and regional SMEs for the elements of power and therefore the ways that intervention is applied, JIIM+DIMEFIL (Joint Interagency Intergovernmental and Multinational+ Diplomatic Information Military economic Financial Intelligence Law enforcement), are required. World and regional SMEs for modeling dimensions, PMESII+PT (Political Military Economic Social Infrastructure Information+Physical environment Time), are required. There is obvious overlap among these SME sectors of knowledge but the scope still remains large. Finally, world and regional SMEs are required for the Themis domains of: Climate, Demography, Natural Resources, Ideological, Economic, Educational, Health and Health Care, Sociological and Globalization.
SME shortcomings are well known. Themis seeks to mitigate SME shortcomings by augmenting their knowledge by: (1) actual data feeds that are emerging from internet and sensor technology breakthroughs and (2) adaptive system technology with SMEs in the loop.

2.3. Alternate Views of the Situation

It is critical to recognize that there are multiple views (concepts, theories and hypotheses) of how a situation in the world, nation, military, climate, economy, etc. operates. By requiring a world model and looking at an extended timeline (25 plus years), Themis has greatly increased the number of distinct and differing theories that may need to be considered in order to understand the scope of future landscapes. For example, there are several global warming and energy resources theories with highly different impacts on potential interventions. There are also a large number of social theories with different significant impacts on future world states. Themis will allow simulations to be run with different concepts, theories and hypotheses in order to understand and compare potential future landscapes.

2.4. Key Conceptual Elements

Guided by JIIM+DIMEFIL and PMESII+PT factors with SME guidance Themis will allow the user to identify and develop conceptual representations and relationships for the major elements necessary for a world model. Themis has identified two key conceptual elements: **Domains** and **Actors**.
Domains are unique fields of knowledge that have global effects with aggregate potential to drive events that might lead to intervention. The aggregate set of Domains is required to cover the space of key world event drivers. Domains have relationships with other Domains and with Actors.
An initial set of domains that is felt to relate to the types of questions posed to Themis would be determined by SME's. For example, in the Joint Operations Environment (JOE, 2010) Demographics, Globalization, Economics, Energy, Food, Water, Climate Change and Natural Disasters, Pandemics, Cyber, and Space were called out as "trends influencing the world's security". Initial domains are expected to include Climate, Demographical, Resource, Ideological, Educational, Health and Health Care, Sociological and Globalization but Themis will be extensible to additional domains as they are identified or emerge as significant drivers. For example the state of a domain is characterized by the value of its associated parameters as each domain is characterized as a function of these parameters.
Actors are decision makers that can influence the state of the system and the actions of the other actors. Actors can be individuals or complex systems such as institutions, organizations, nations, coalitions, multinationals, cartels, etc. Actors have relationships with Domains and other Actors.

3. CONCEPTUAL MODEL

Themis includes an analysis module, a data repository, a user interface and a scenario generator. The Themis Repository shall have a well defined ontology and be able to receive data from tools outside of Themis. Once a problem is posed to Themis, it goes through the process of "Problem Formulation". This indicates that it translates the data provided to map to the parameters used to characterize the domains as well as the actors. It further does preliminary analysis to determine the driving parameters in each case and provide high level insight about the system behavior. The next step is to provide this formulated problem to each of the actors and system models for further analysis. Each of these models may use one or more techniques (which may be within the Themis toolbox or may also be outside tools that Themis interfaces with.). When each of these separate layers has been analyzed separately, the information from the analysis is fed into the Themis simulation module. The Themis simulation module will then combine this information and projects it into the future. This information will in turn be fed into the scenario generator which includes modules for uncertainty analysis and aggregation of probabilities in order to propagate uncertainties through the latest system model to determine the likely future scenarios and their associated probabilities. This proposed architecture is shown in Figure 1.

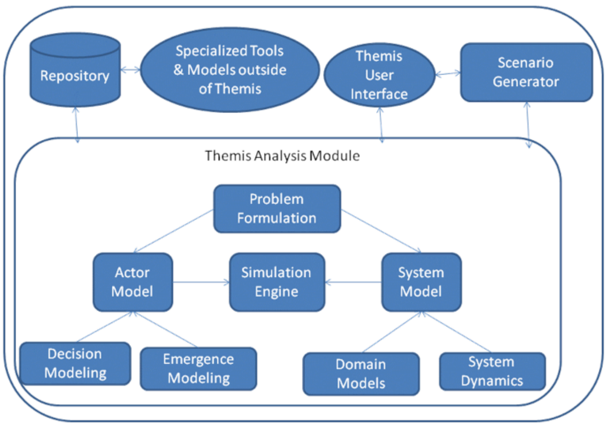

Figure 1: Themis Operations Concept Viewpoint

Figure 2 shows another example viewpoint for the Themis methodology. This viewpoint demonstrates three layers that inter-operate. The lowest level is the system topology. This layer performs the function of representing the system structure. Each of its modules represents a domain of the system or a data source that helps characterize a domain. These domains include the economics, demographics, etc., and different data sources such as the CIA fact-sheet and various reports and databases available. The next layer is the actor decision making layer which performs the function of representing the behavior of key actors. This layer has three modules. One module determines the goals of the actors. Another module the key issues that arise and the interaction between actors as they relate to the resolution of these issues. The third model describes the attitudes of actors with respect to various happenings in the world described in the lowest level. The topmost layer serves to represent the system outcome which is based on the performance of the two first layers. This layer uses relevant information from other layers to conduct analysis and generate the possible scenarios for each part of the world and the likelihoods associated with each of those scenarios. This viewpoint also shows an experiment manager. The experiment manager is responsible for orchestrating the activities of Themis by taking as input the request from the customer and finding a path through Themis that helps to achieve that request.

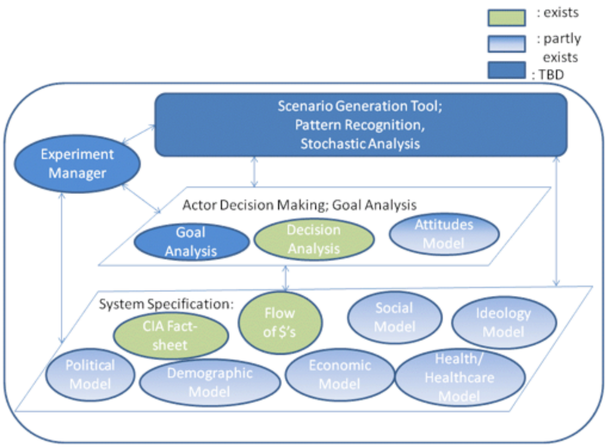

Figure 2: Themis Alternate Viewpoint

Figure 3 shows another perspective on the Themis architecture. Here the Data Analysis layer is shown in tandem with the Themis analysis process. The idea is that the state of the data available is always changing and there is a constant need for analyzing the data and understanding the latest trends and events. This is done outside of Themis and made available to the Themis knowledge/data repository. This repository then makes the data available for the Themis process to run. The Themis user will also create a seed scenario from which the problem definition is created within Themis. The goal and decision analysis then takes place, along with system state analysis. These two are then combined to create the multiple outcomes based on the initial user input and stochastic modeling techniques are used to develop the likelihood of each of these possible outcomes.

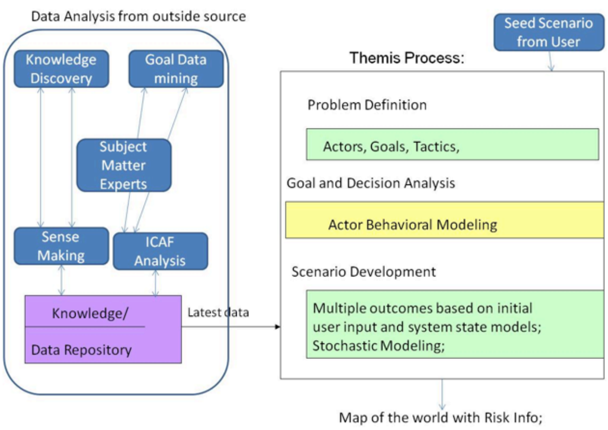

Figure 3: Themis Viewpoint 3

Figure 4 shows a summary of the Themis modeling framework. Themis modeling will be conducted in order to support decisions related to planning, procurement, changes that may occur and force structure. The different types of models that could be used to support Themis can broadly be categorized into actor behavior and domain models and models used for integrating the two. The underpinnings of the actor models are based on social science theories that explain both the actor behaviors as individuals and the social system behavior. The underpinnings of the more physical characteristics of the world, such as climate or demography, are based on science theories. Data used to exercise these models is obtained from the news, or from classified data sources. The history that is relevant to the problem being addressed is obtained from narratives or relevant world scenarios.

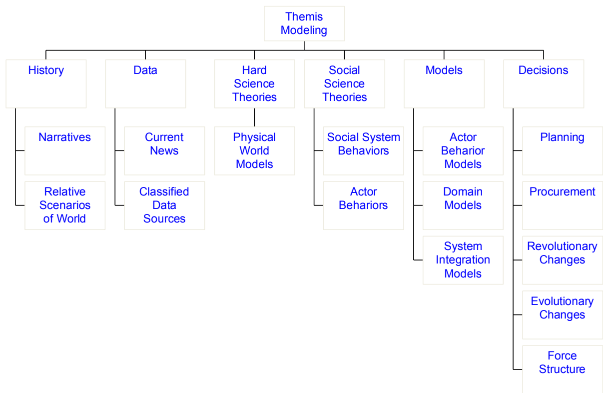

Figure 4: Summary of Themis Modeling

4. THEMIS DEVELOPMENT

The first step in development is building a stand-alone "Themis Central" which includes a set of experts using Themis as a tool for conducting multiple types of studies conducting historical use cases examining major trends of the past would be the first set of studies recommended as they help validate the underlying models. The second step is automating some of the functions of the "Themis Central" team so that the interaction between various specialized tools and subject matter experts is semi-automatic. This approach considers Themis to be a member of an interconnected suite of models. These models include other specialized tools and techniques outside of Themis. These tools and techniques are determined by the problem being posed and collaboratively picked by the experts conducting the study.

4.1. Central team

The process by which this team operates is shown in Figure 5. This process and team configuration is inspired by the spacecraft conceptual design process used in JPL's concurrent, conceptual design team, TeamX. The customer of the study initially meets with the Themis Central team lead and systems engineer to define the problem of interest. Together the customer and the team leads determine the scope of the study needed to address the problem. It may very well be that an initial study is conducted by the systems engineer and systems modeler with Themis to help the customer scope the problem and determine where they need to focus. Once the problem is well defined, the relevant domain experts are brought in as appropriate. The systems engineer is responsible for designing the study and breaking down the problem into parts to be performed by each of the experts involved. The systems modeler builds the high level systems models within the Themis environment and interfaces with the domain experts as necessary. These two roles may be performed by the same person on small studies. Each of the domain experts work with the systems engineer and system modeler to formulate the problem they need to focus on within their own area of expertise. They then use their expert knowledge as well as specialized tools to analyze this problem and interface with the systems modeler as appropriate.
The transfer of data and information between the various experts and the corresponding models may initially occur manually. As the process becomes well established, the transformations between the different tools and techniques are more and more automated and an underlying data structure and repository is created for the automatic transfer of this information.
Themis will be the tool used by the Systems Modeler in building high level models. The data sources and lower level models that may be required for providing the inputs and insight regarding what experiments to design within Themis to address the questions being posed by the customers are included in the library of tools and techniques used by domain experts.

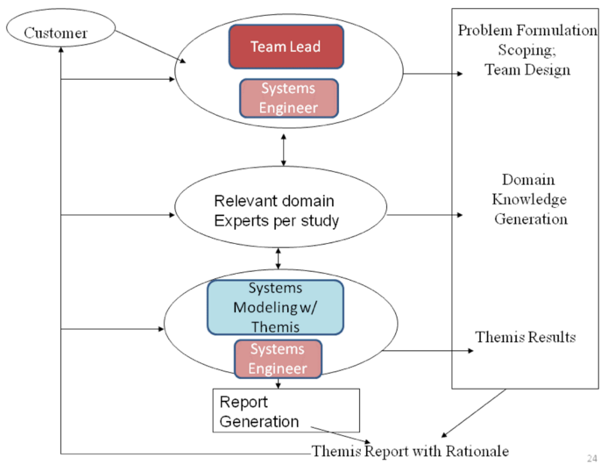

Figure 5: Themis central Team Process

Studies are often conducted iteratively, with the customers and the team leadership reviewing the interim results and identifying the next steps for the study. Once a set of Themis runs are performed, the study lead will synthesize the results to address the questions posed by the customer. Once a set of reasonable answers are created, the results are summarized in a report and provided to the customer. Table 1 summarizes the different suggested roles for a

Themis central team and their corresponding functions and responsibilities.

Table 1: Central Team Roles and Responsibilities

Role	Function/Responsibilities
Customer	•Defines scope of study, duration, results and requirements.
Team Lead	•Works with customer to develop study plan. •Works with Systems Engineer to coordinate and plan the team. •Leads team activities and studies. •Synthesizes the results. •Makes executive decisions about direction of the study as it is proceeding.
Systems Engineer	•Works with team lead and customer to define the study. •Creates overall design for study. This includes defining the scope, experiments to be conducted and iterations between the Themis model and domain models.
Systems Modeler	•Develops Themis models. •Works with Systems Engineer and domain experts to incorporate their information.
Domain Expert	•Works with systems modeler and systems engineer to define domain problems. •Uses specialized domain tools to develop models and solutions for domain. •Iterates with systems modeler for Themis design.

As a problem is posed to Themis, it will use the history related to the problem, the data sets and modeling techniques applicable, current information and the social theory underpinnings that are chosen for the analysis. The models may correspond to the social theories in question. For instance, William Bernstein states in "The Birth of Plenty" (Bernstein, 2010) that there are four factors necessary for a nation to become wealthy: property rights, scientific rationalism, capital markets, and fast and efficient communication and transportation. This could be one model of the state of the economic domain.

The user of Themis or the orchestrator will pick their preferred social theory and corresponding models. For instance, they may pick the history and data related to a specific country and the model that is based on Bernstein's social theory to predict the economic status of the country. The best models for the user to pick would depend on the problem being addressed. There would exist in-depth domain models for each of the domains of interest. Once the right models and knowledge/data bases have been used for their corresponding analysis, it is time to formulate the problem to be solved within the Themis environment. Themis will include high level models of all the relevant domains and is able to combine the results obtained from each specialized model or database to provide insight into the state of the overall system which is the world. The process of using Themis as a member of the orchestra is shown in Figure 6.

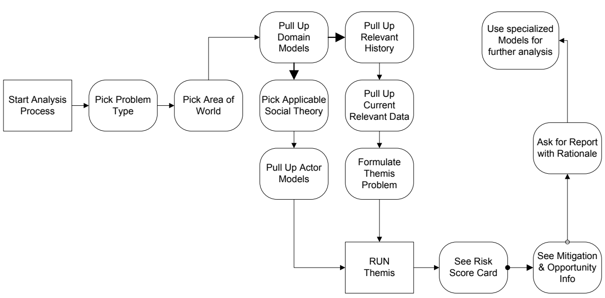

Figure 6: Themis As a Member of the Orchestra

4.2. Themis As Orchestrator

Ultimately the intention is that Themis be used as the principal integrator and user interface. Themis will have the ability to automatically combine the data obtained from other models and make the transformation to its repository for Themis modeling. Furthermore, Themis will provide access to other tools and techniques for the user to work with. Note that the key distinction between when Themis is the orchestrator versus when Themis is a member of the orchestra is that the various modeling steps are automatically done by the experiment manager within Themis when Themis is an orchestrator.

Two use cases are shown in Figures 7 and 8. In both of these cases, the user starts by opening Themis and then picks the problem type and relevant domain models, social science theories and other knowledge bases directly from Themis. In the background, there is an intelligent system manager that works with the user to help define the necessary data and models necessary to formulate and solve the problem in Themis. Iterative loops occur within the Themis environment. For instance, in Figure 7, the user decides to change the relevant social science theory and re-run the model.

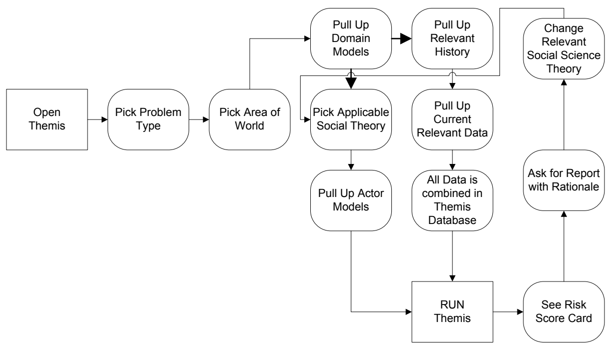

Figure 7: Themis As An Orchestrator (1)

In Figure 8, the user decides to insert additional actors into the system to see how that ripples through.

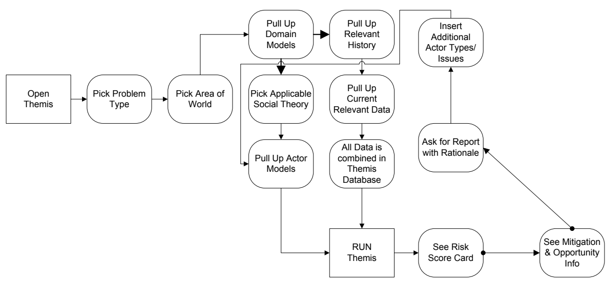

Figure 8: Themis As An Orchestrator (2)

5. DEMONSTRATIVE EXAMPLE

For demonstrative purposes, let's consider a simple nominal example. The problem is assessing the likelihood of intervention associated with a country X within the next 25 years. The first step is to characterize that country with parameters associated with its domains.

Either exact or approximate values for each of the parameters of interest over the last 20 years are collected from the existing databases. Figure 9 depicts these key relevant parameters and some of the relationships between them. The complete set of relationships between the various parameters is given in the adjacency matrix shown in Table 2. A "1" in the cell at the intersection of the row and column of the matrix between two parameters indicates that these parameters are related. As it can be see, this is quite a sparse matrix. Therefore, it's very likely that the number of significant variables can be reduced. The next step is to conduct a Principal Component analysis (Draper and Smith, 1998) to determine the key independent variables. Let's assume these key variables include migration, GDP, literacy, religious education, status of women, level of health and potable water. These variables are shown in bold in Figure 9.

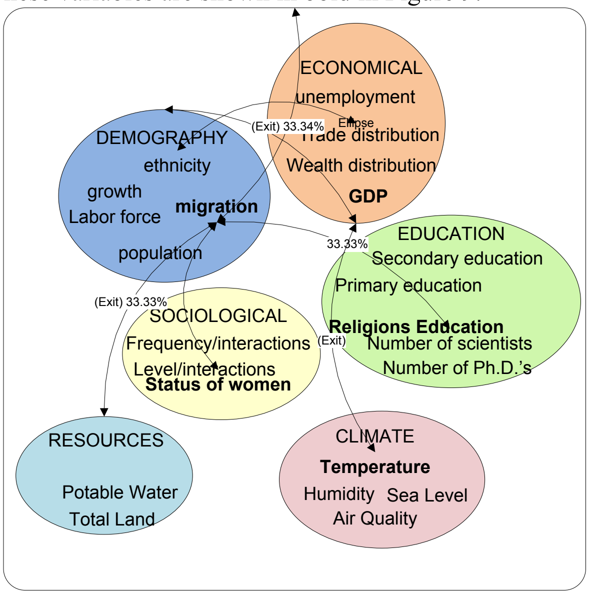

Figure 9: Parameters and Influences for Country X

Further statistical analysis of data associated with these parameters for the last 20 years indicates the type of effect they have on each other. This is shown in table 3. At the intersection of the row "migration" and the column "GDP" there is a "-" sign. This indicates that an increase in the variable "migration" causes a decrease in the variable "GDP". There is a "+" sign at the intersection of the row "status of women" and the column "level of health". This indicates that based on the existing data, an increase in the status of women causes an increase in the level of health. Therefore the key parameters of significance and relationships between them are obtained by analyzing existing data. It's possible to extrapolate this data to assess the state of these key parameters over the next 25 years. But the state of the world depends not only on the trends associated with the domains, but also the behavior of key actors for country X.

Table 2: Adjacency Matrix for Country X

COUNTRY X

		Demography						Economical					Educational								Healthcare				Sociological				Resources		
		population	growth	**migration**	ethnicity	labor force		**GDP**	unemployment	wealth distribution	trade distribution		primary education	secondary education	tertiary education	**Literacy**	number of scientists	number of Ph.D.'s	**Religious Education**		**Level of health**	coverge of health care	life expectancy		frequency of human interactions	level of human interactions	**status of women**		Arable Land	Total Land	**Potable water**
	population	1						1								1					1										
	growth		1																												
	migration			1				1																							1
	ethnicity				1						1					1															
Demography	labor force					1		1																	1		1				
												1																			
	GDP			1				1								1			1		1						1				1
	unemployment								1					1										1							
	wealth distribution						1			1																					
Economical	trade distribution										1					1									1						
																	1	1													
	primary education							1					1									1					1				
	secondary education													1																	
	tertiary education														1																
	Literacy			1				1								1					1						1				x
	number of scientists																1						1								
	number of Ph.D's.											1																			
Educational	**Religious Education**			1				1								1			1								1				
											1													1							
	Level of health			1				1								1					1										1
	coverage of health care																					1									
Healthcare	life expectancy																1						1								
	frequency of human interactions																								1						
	level of human interactions										1															1					
Sociological	**status of women**			1				1					1			1			1		1						1				1
	Arable Land																												1		
	Total Land												1				1													1	
Resources	**Potable Water**			1				1													1										1

Table 3: Relationship Between Key Variables

	migration	GDP	Literacy	Religious Education	Level of health	status of women	Potable water
migration	1	-	-		-	x	+
GDP	-	1	+	-	+	+	+
Literacy	+	+	1	x	+	+	x
Religious Education	+	-	+	1	x	-	x
Level of health	-	+	+	x	1	x	+
status of women	-	+	+	-	+	1	+
Potable Water	-	+	x	x	+	x	1

Based on existing data, as well as subject matter expertise, the actors associated with that region are classified into three different types A, B and C. Each type is characterized by a set of parameters as well as a main goal. In order to determine the relative influence of each type of actor and hence the most likely state of the system, the goals of each actor are articulated using a linear objective function. The constraints associated with the domains are also articulated and the set of linear equations and constraints is solved via Linear and Goal Programming approaches (Scniederjans, 1995).
These set of equations are given values of the domain parameters associated with the point in time which is of interest. Since the values of the parameters were assessed for the next 25 years, the level of goal attainment of each actor, which in this case corresponds to the is increasing the wealth and population of their respective supporters is obtained by solving the Linear Programming problem.
Given the level of goal attainment for each actor and the basic understanding about the country in question from related data (which includes historical data and expert

information), the Themis modeling engine will be able to then generate the scenario which leads to a high risk state and will conduct probabilistic analysis to determine the likelihood for intervention.
Figure 10 illustrates one such scenario. Religious dogmatism causes a reduction in GDP as well as a reduction in the status of women. Water shortage in turn causes disease and migration. Migration causes a reduction in GDP as does the decrease in the status of women. As the migration increases, the average level of education within the society decreases and this in turn causes a reduction in GDP as well. Once the GDP becomes lower than a certain threshold, there is civil unrest that causes the government to lose control and necessitates intervention. Using the available trends and data, Themis will estimate the value of the probabilities associated with the root events and the conditional probabilities associated with the other events to build the Bayesian Belief Network (BBN) associated with this scenario. Solving this BBN using the estimated probability values indicates a 62% chance of the need for US intervention. These values are shown in Figure 11.

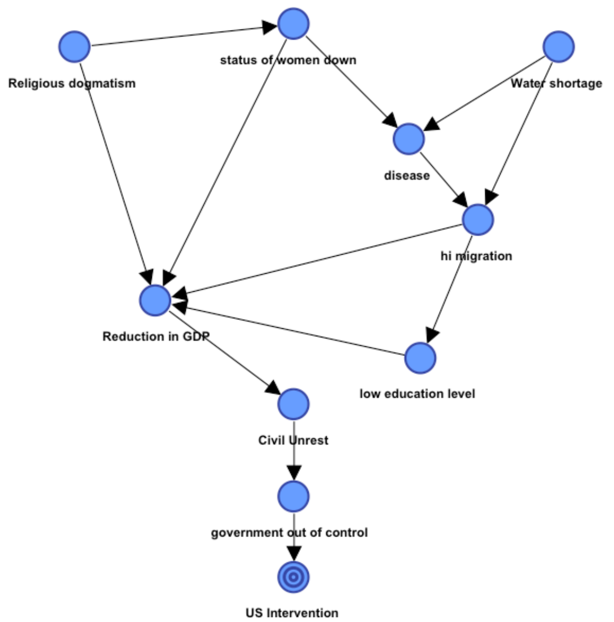

Figure 10: Scenario and Associated BBN

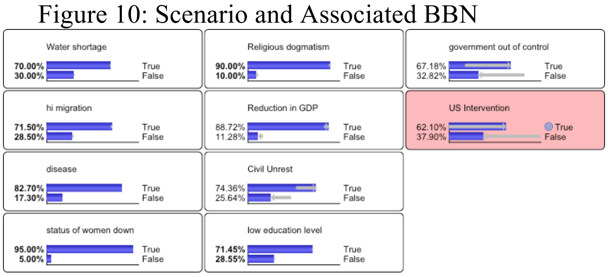

Figure 11: Probability Distribution for the BBN

6. CONCLUSION

The key features of this paper include:

- Re-phrasing of the original problem statement into risk and opportunity analysis which can be modeled.
- Summarization/extrapolation of trend analysis relating to the future expectation of the Joint Operational Environment for the Army.
- Adding dimensions to the definition of risk. These dimensions include measures for the direction and acceleration the risk is taking. Seeks to represent the problem space with a few key parameters.
- Partitioning of the problem space into two fundamental layers (actor and domain).
- Preliminary classification of actors and key drivers for their decisions.
- Preliminary assessment of how different "types" of actors emerge and how emergence is interdependent on the state of the domains.
- Defining a team structure based on JPL's experience in engineering of large scale, complex spacecraft with multi-disciplinary teams.

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INTELLIGENT AGENTS & INTEROPERABLE SIMULATION FOR STRATEGIC DECISION MAKING ON MULTICOALITION JOINT OPERATIONS

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ABSTRACT

This paper proposes an innovative interoperable federation developed for addressing strategic decision making on multi-coalition operations. The proposed architecture integrates several different simulators in HLA and is open to be operated in different modes from stand alone basic installation to fully integrated with entity based simulations. The simulator uses Intelligent Agents to reproduce human behavior and human factors as well as discrete event simulation paradigm into virtual and constructive environment.
The paper describes the models as well as the approach to address the problem; some experimental results related a realistic scenario are proposed as well as the different a solutions adopted to support Commander engagement in using this kind of simulation.

Keywords: *Intelligent Agents, Human Factors, High Level Architecture, Multi-coalitions, Joint Operations*

INTRODUCTION

Currently most of existing humanitarian and normalization operations are carried out by international organization; in facts today most of the military operations carried out overseas have to face interaction with civilians in different roles, such as refugees, immigrants, internally displaced persons, etc. (Main 2009; Bruzzone, Sokolowski 2012); the dimension of the situations to be addressed as well as the socio cultural economic context are normally so big that it is pretty common to operate by multi coalition with specific goals and interests that interact in the same area by involving entities such as United Nations, NATO, EU, Nations (e.g. Russia, China), Red Cross, Red Crescent Moon etc.
In these context the human factors are often the main aspects as happen in recent scenarios such as Lybia, Afghanistan, Syria (Johnson et al. 2008, Bellamy & Williams 2011; Dewachi et al. 2014). For instance the HBM (Human behavior modifiers) that include fear, fatigue, stress, aggressiveness as well as need for food, water, health care and security strongly influence the behavior of both military forces (including also opposing force) and population both locally and domestically (Gartner & Segura 2008; Kreps 2010; Bruzzone et al. 2013b). The rational and emotional behavior of the people within the scenario is another crucial (Bruzzone et al. 2011a). Examples from operations in different cases from piracy to CIMIC, from country reconstruction to Disaster Relief confirms that the use of simulation integrated with human behavioral models is key issues for proper decision making (Bruzzone et al.2010, 2011b). Simulation Team developed since 2001 intelligent agents to be used to address these issues; in particular IA-CGF (Intelligent Agents Computer Generated Forces) has been successfully applied over a wide spectrum of applications and tailored for different socio-cultural frameworks (Bruzzone 2013a). So they have been used just to address specifically multi-coalition joint operation and to create an interoperable simulation over this mission environment as done for other cases (Bruzzone et al. 2012).
Due to these reason the creation of interoperable simulation integrating all these elements represents an important achievements for supporting decision making on issues related to human factors withincomplex scenarios.
The authors propose here these models in relation to project devoted to create a simulator for immersing a Commander in a comprehensive scenario where human factors are decisive (Bruzzone et al. 2014a).
The research is related to SIMCJOH (Simulation of Multi Coalition Joint Operations involving Human Modeling) project that was developed under coordination of Simulation Team, DIME, Genoa University in cooperation with CAE, Cal-Tek, MAST, MSC-LES University of Calabria and Selex (Bruzzone et al. 2014a).

Fig. 1 SIMCJOH_VIS Main Window. Presents the situation and the events to the User and all major commands

This paper focuses on the SIMCJOH federation and in particular on SIMCJOH VIS (Virtual Interoperable Simulator) and SIMCJOH VIC (Virtual Interoperable Commander) that are the two main simulator developed by simulation team for directing the simulation and managing the human factors.

1. DEALING WITH OPERATIONS AFFECTED BY HUMAN FACTORS: SIMULATION AS ENABLING SOLUTION

To model complex operations involving population and human factors is a challenge and requires the tailoring of HBM for the specific scenario; indeed in this case the mission environment is related to SIMCJOH project; therefore the authors had experience in modeling M&S in many different regions as well as in Middle East context already (Bruzzone et al. 2014a); SIMCJOH was devoted to carry out R&D activities with the aim of understanding at which extent interoperable simulators are effective and efficient within a multi-coalition context for supporting the Commander and his Staff to in addressing and solving specific problems strongly dependent on human factors.
Indeed Modeling & Simulation (M&S) makes possible recreating complex scenarios and carrying out what-if analyses with the aim of evaluating the effectiveness of several alternatives (Course of Actions, COAs). By this approach it is possible to develop training aids and even briefing supports able to immerse the Commander and his Staff into a virtual scenario driven by the Intelligent Agents (IA) that evolves dynamically and react to the decisions and actions in real time or fast time.
For this purpose SIMCJOH was developed as an interoperable Federation able to operates in multiple modes; for instance SIMCJOH could run in stand-alone mode for being used simply and quickly by the Commander on his own laptop to improve effectiveness of briefings when he is assigned to a new command and/or in a new geopolitical area. As alternative SIMCJOH could be fully federated through HLA (High Level Architecture) integrating entity level simulation, scenario generators, communication networks, C2; in this case SIMCJOH could be a dynamic element of a CAX (Computer Assisted Exercise) and introduce strategic issues and human factors within a large scenario. SIMCJOH adopt the innovative paradigm MS2G (Modeling, interoperable Simulation and Serious Game) for guarantee easy distribution of the simulator; indeed in this case the main simulator is able to interact through the web and it could even run within a browser (Bruzzone et al.2014b).
Such concepts benefit of previous experiences in web based simulation (Bruzzone et al. 2008, 2009a, 2009b); these SIMCJOH_VIC indeed is a serious game devoted to immerse the Commander into a 3D environment synchronized with SIMCJOH_VIS Scenario evolution and able to provide also video stream from drone point of view; this approach allows to overpass traditional serious games and to adopt new uses for these applications such as crowdsourcing and virtual experiencing complex systems (Rayburn 2012; Tremori et al. 2014)

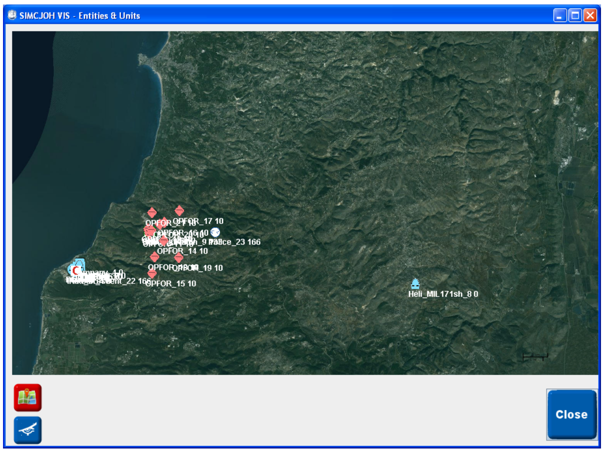

Fig. 2: SIMCJOH VIS Tactical Representation Window

2. VIRTUAL INTEROPERABLE SIMULATOR

The authors developed, for the above described application case, an innovative model defined SIMCJOH_VIS (Virtual Interoperable Simulator) which adopts stochastic discrete event simulation to generate simulation events, human behavior models, population reactions, unity actions and conditions that are shared over SIMCJOH federation.
SIMCJOH_VIS simulator in a specific NCF (Non Conventional Framework) of IA-CGF (Intelligent Agent –Computer Generated Forces) which drives the units and active entities within SIMCJOH federation. This simulator is in charge of reproducing emotional, rational and social behaviors of entities and units and, even, to interact with the Virtual Assistants that are reproducing virtually his staff. Indeed the Virtual Assistants are proactive IA proposing to the Commander problems and open issues, as well as possible solutions in terms of alternative COA; these IA execute Commander's decision; in addition to that they actively react to Commander requests.

Fig. 3: SIMCJOH_VIS Popup

These processes are simulated considering stochastic time and resources required to identify the problem, prepare the alternatives and present them to the Commander as well as to assign operational orders.
Most of the events generated and managed by SIMCJOH_VIS are presented by other federates (e.g. tactical situation, C2 representation, virtual immersive 3D environment), therefore to support easy quick stand alone mode SIMCJOH_VIS proposes also its own intuitive dynamic graphics (see figure 1); in this case the crisis representation as well as boundary conditions (e.g. daylight, sensor view, population status) as well all the events are proposed; events are represented as pop up while also a sequential storyline is generated stochastically in consistency by the simulator during the evolutions of the events.

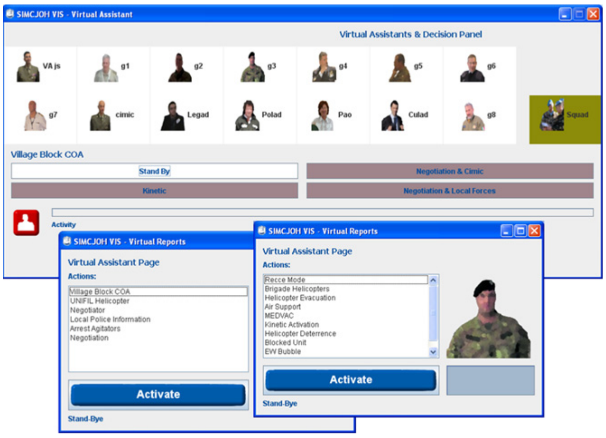

Fig. 4: SIMCJOH_VIS Virtual Assistants

3. SIMCJOH_VIS FEATURES

SIMCJOH_VIS includes Entity Simulation Models and it allows to simulate different kind of entities and units; these entities could be represented over a very basic tactical framework within SIMCJOH_VIS even if tactical and virtual representations are supported by other simulators federated within SIMCJOH Federation in HLA. SIMCJOH_VIS considers the use of entities for many different assignments including "force to force" actions; therefore these agents drives also other entities such as paramilitary units, ambulance and NGO, demonstrations etc. The simulated entities are characterized by several information including among the others. Indeed Figure 2 presents a very basic tactical representation of the on-going situation.

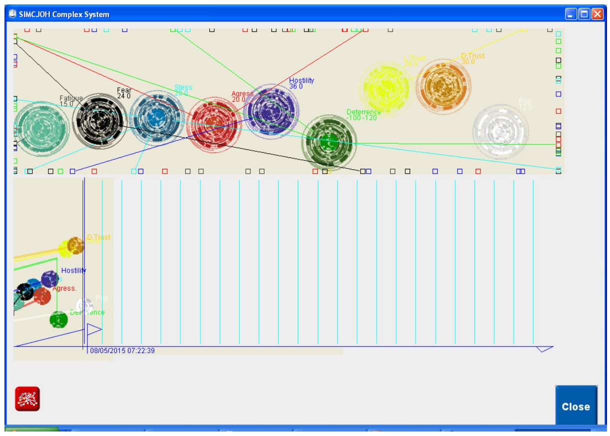

Fig. 5: Graphic Dynamic Representation

In figure 3 are reported examples of two Pop-up generated dynamically by SIMCJOH_VIS during the Simulation (corresponding to info distributed over HLA).
In figure 4 is shown the Virtual Assistant. It is possible to interact with the VA through the SIMCJOH_VIS Virtual Report and then, eventually, to decide about any current issue.

4. HUMAN BEHAVIOR MODIFIERS

As shown in figure 5, SIMCJOH_VIS proposes the dynamic evolution of HBM (Human Behavior Modifiers) along each simulation run; these objects proposed corresponds to the main human factors and how they are controlled by IA-CGF; similar events are proposing also decisions, actions and emerging behaviors.
In figure 6 in the upper part the graph proposes the different variables as ball elements; these include from left to right:
Fatigue - Fear - Stress - Aggressiveness - Hostility - Deterrence - Local Trustiness - Domestic Opinion - Demonstration Size

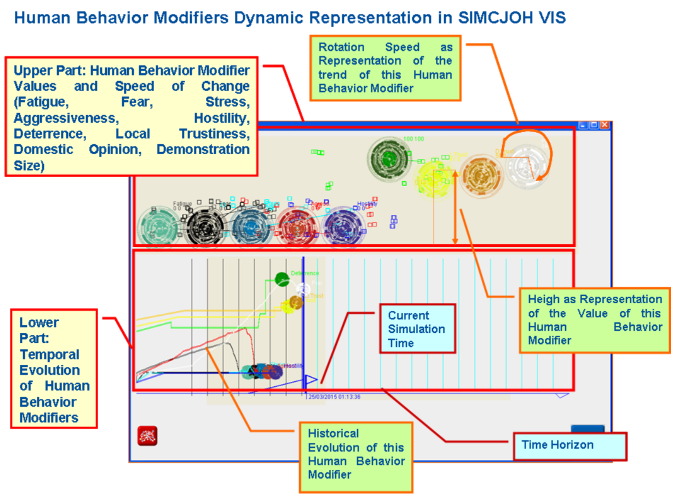

Fig. 6: HBM Dynamic Representation

Each ball element rotates based on their change rate and moves up and down based on their intensity; the value are pure numbers corresponding to a relative scale going from zero to 100 for Fatigue, Fear, Stress, Aggressiveness, Hostility; the relative scale used moves from minus 100 to plus 100 for Deterrence, Local Trustiness, Domestic Opinion in terms of positive and negative deterrence respect opposite size; Demonstration Size is scaled between zero to 1000 people.
Small Squares are generated and moved, in this figure, toward these different Human Behavior Modifiers (e.g. stress, fatigue, etc); each of this square represents an event or action that is increasing/decrease these modifiers. Vice versa, in the lower part of the window the graph presents the same factors as balls, but it reproduce their behavior in terms of temporal evolution along simulation time horizon as well as their trends; this support the users in understanding the situation evolution as well as in identifying the critical changes in population behavior corresponding to crucial events and effects of decisions. Temporal evolution of target function is also available (ASCII file in format CSM).

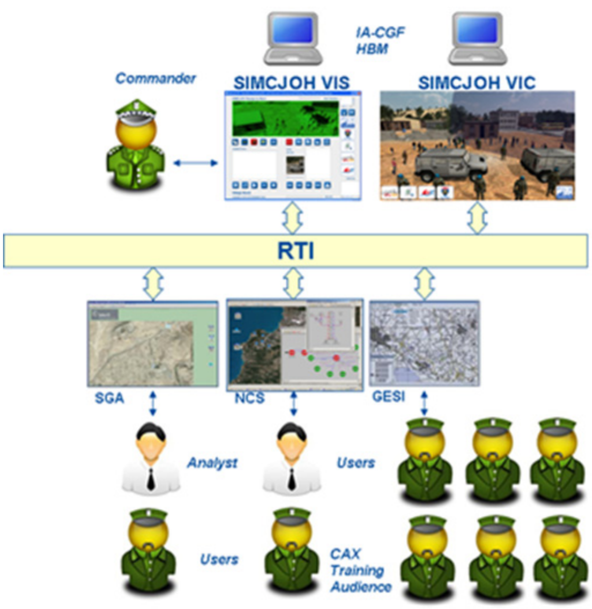

Fig. 7a: SIMCJOH Federation in full operative mode for CAX

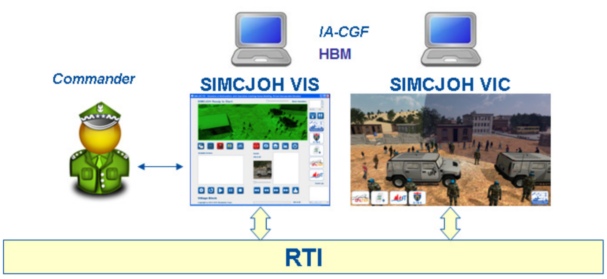

Fig. 7b: SIMCJOH VIS and VIC federated locally (e.g. same machine)

5. HIGH LEVEL ARCHITECTURE

SIMCJOH_VIS operates as main element of SIMCJOH Federation and drives the whole scenario evolution; currently it was tested operating with Pitch and Mak, but also portico was tested; SIMCJOH_VIS is operating mostly in Windows environments even if testing were conducted on Linux and Mac. The SIMCJOH architecture is proposed in figures 7a and 7b.
The propose simulator allows to change the configuration to allow proper initial setting in reference to eventual limitation of other federates,
HLA Configuration for this simulator includes:

- Federate Name
- Federation Name to Join
- RTI Engine to be used, currently supporting Mäk, Pitch and Portico
- IP Address
- Port Number
- Synchronization Point Mode and Number of Federates to wait as well as Synchronization Object Name
- Date and Time to use as offset for Simulation in HLA mode

In order to guarantee the interoperability amond the different simulators, it was introduced a specific interaction defined as PlayerMessage to be made available in SIMCJOH format and in JSON (JavaScript Object Notation) format.
Both formats could be activated concurrently generating in HLA multiple messages for same event.
SIMCJOH_VIS includes other possible elements devoted to change Simulation Setup through the following variables:

- Duration of the Simulation [h]
- Offset that represent the starting time and date for the simulation in standalone mode.

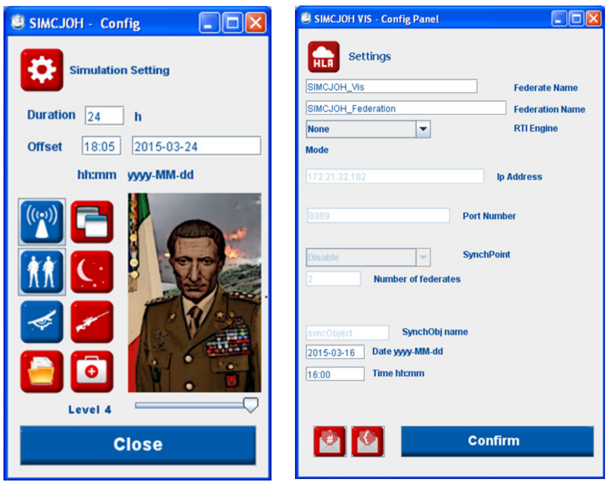

Fig. 8: Simulation Setup and HLA Configuration

6. SCENARIO

The context for testing SIMCJOH is identified in Middle East area over an hypothetical country named Eblanon where United Nation (UN) are active by a multi-coalition mission; the case study address the Commander of an Italian army Brigade that is responsible an area; the scenario includes events that, despite their small entity, have strategic relevance for the contingent and the multicoalitions; in this paper is proposed the case that a squad is blocked into a village and requested by civilians to surrender their weapons; considering the UN mandate and ROE it is evident the critical impact of such decision; the simulator regulates this scenario adding many possible elements such as presence of domestic or local media, mobile coordination, presence under coverage of insurgents and or snipes, possibility to access the area by helicoters, previous CIMIC in the village and their success, etc.
Baseed on this scenario and on available resources the Commander could decide different courses of actions , eventually tailoring them, while the IA driving his staff (e.g. J2, J3, CULAD, POLAD, PAO etc.) support his decisions and direct the simulation evolution as well as the IA ruling other parties (e.g. population, local authority, religious authorities, bordering countries, insurgents, etc.). The nature of this area of Middle East is pretty interesting considering the large difference of ethnics, religion, social status, education, etc. In addition to these elements the presence of different players (e.g. Local Authorities, Health Care, Red Crescent Moon, Other Coalition Partners having specific equipment, etc) forces the Commander to understand the correlations among different actotrs.

7. EXPERIMENTAL ANALISYS

SIMCJOH_VIS was subjected to formal, informal and dynamic VV&T (Verification, Validation and Testing); the model was presented and discussed with military experts involved in the specific scenario used for the experimentation; in addition the data collected by multiple simulation runs were used within ANOVA (Analysis of Variance) by applying Design of Experiments (Montgomery 2008). In facts, the SIMCJOH experimentation is focusing on identifying the behaviors of target functions mapped by the simulator; this analysis represent an example of how Design of Experiments and Sensitivity Analysis allows to evaluate the impact of the independent variables on the target functions.
Concerning with the experimentation execution and the simulation results, an example of techniques and methodologies to be used for studying results consistency has been provided. In particular Mean Square pure and Sensitivity Analysis are carried out for the different alternatives..
The analysis of MSpE (Mean Square pure Error) is a consolidate techniques supporting ANOVA both in terminating and steady state simulations; indeed MSpE measures the variance of the target functions among replicated runs over the same boundary conditions; by this approach it becomes possible to identify the number of replications and the simulation duration able to guarantee a desired level of precision; MSpE values in correspondence of these experimental parameters determines the amplitude of the related confidence bands. Vice versa Sensitivity Analysis allows to identify the influence of different parameters or choices respect specific target functions; for sensitivity analysis hereafter are synthetized the main alternative COAs:

- ***Stand By***: The Commander requests to wait for further evolution
- ***Negotiation & CIMIC***: Using CIMIC and previous activities in the area to negotiate with locals about stopping the crisis
- ***Kinetic***: The Commander request to prepare military units in stand by and to force the demonstrator to desist by applying controlled deterrence
- ***Negotiation and Local Forces***: The Commander requires support from Local Police Authorities for negotiating with the population and solving the problem.

$$MSpE\ (t,\ n_0) = \frac{\sum_{i=1}^{n_0} x_i(t) - \bar{x}(t)}{n_0} \qquad \bar{x}(t) = \frac{\sum_{i=1}^{n_0} x_i(t)}{n_0}$$

t	simulation time
no	number of replications with same boundary conditions and different random seeds
MspE (t,no,)	Mean Square pure Error at t time

In fact the MSpE allows to quantify the experimental error due to influence of the stochastic components respect the required replications or durations for obtaining a stabilization; so by this approach it becomes possible to estimate the confidence bands on the different target functions. For instance, considering the Aggressiveness Level of Population related to the 4 different commander decisions, the MSpE (Mean Square pure Error) was computed by carrying out replicated runs over the same boundary conditions.

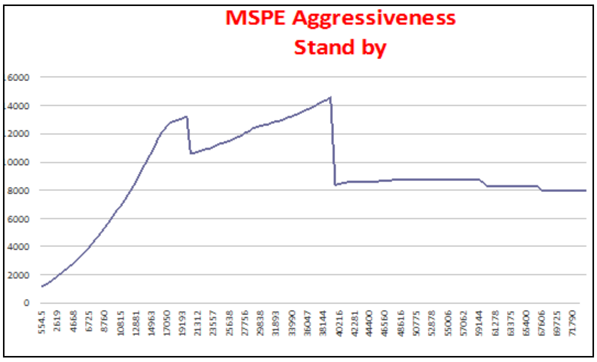

Fig. 9: Decision to Stand By during the Crisis– Stand By

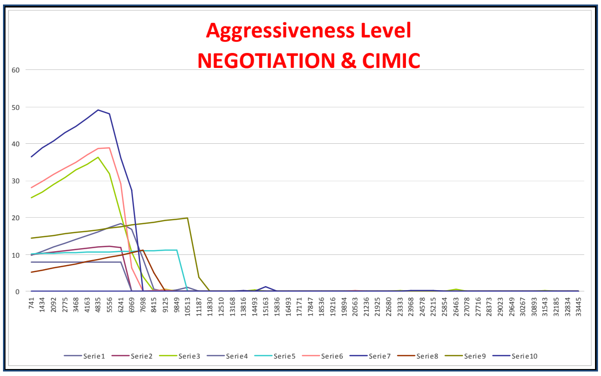

Fig.10: Option 1 – Negotiation & CIMIC: Results of Different Runs

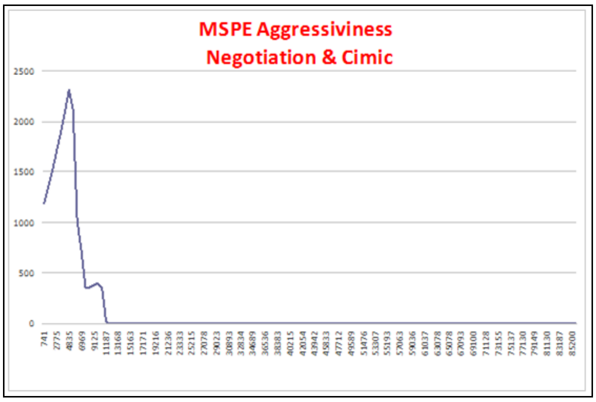

Fig. 11: Option 1 – Negotiation & CIMIC - MSpE

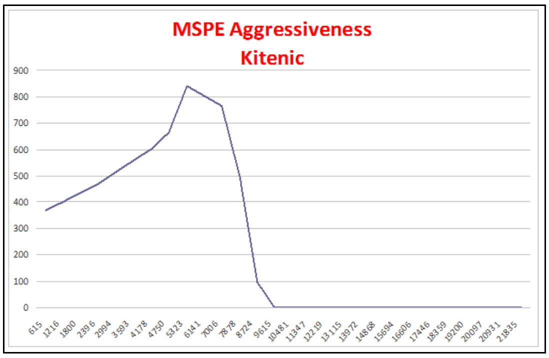

Fig. 12: Option 2 – Kinetic MSpE

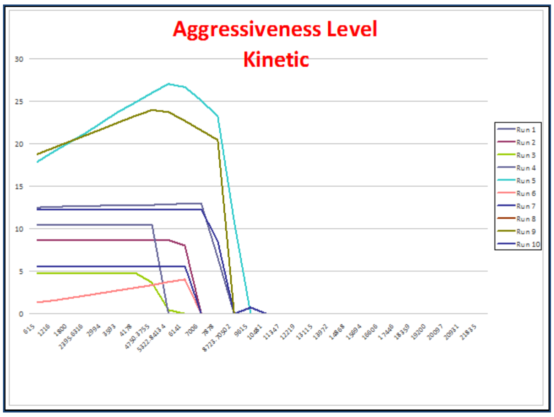

Fig. 13: Option 2 – Kinetic Replicated Runs

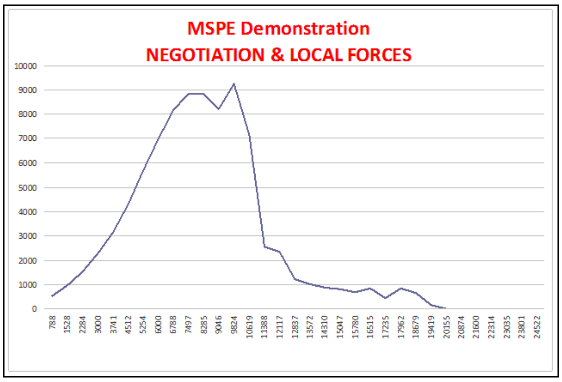

Fig. 14: Option 3 – Negotiation & Local Forces MSpE

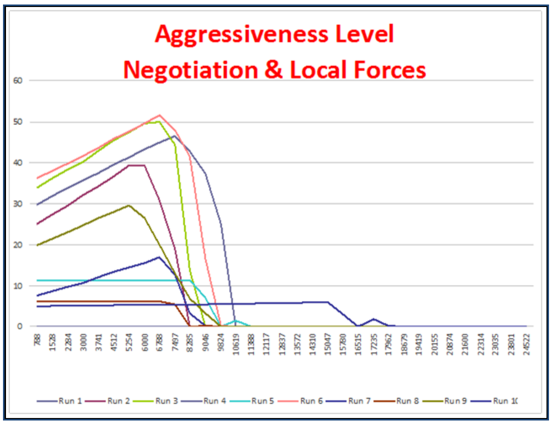

Fig.15: Option 3 – Negotiation & Local Forces Replicated Runs

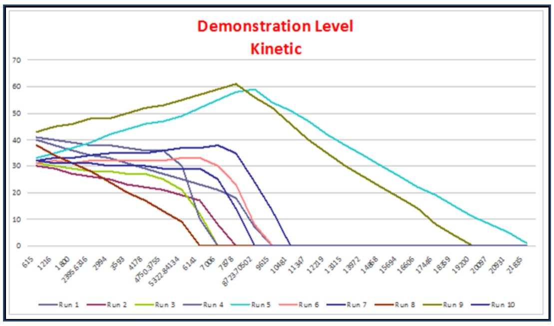

Fig. 16: Option 2 - Kinetics different End States - Number of Demonstration

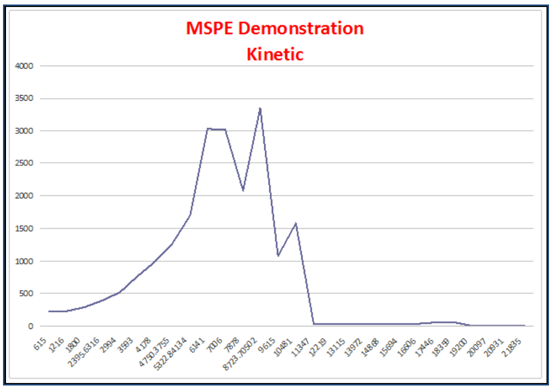

Fig. 17: Option 2 - MSpE among Converging Runs

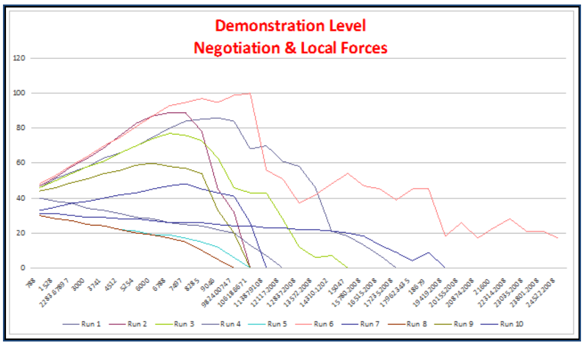

Fig. 18: Option 3 - Negotiation and Local Forces - Number of Demonstration

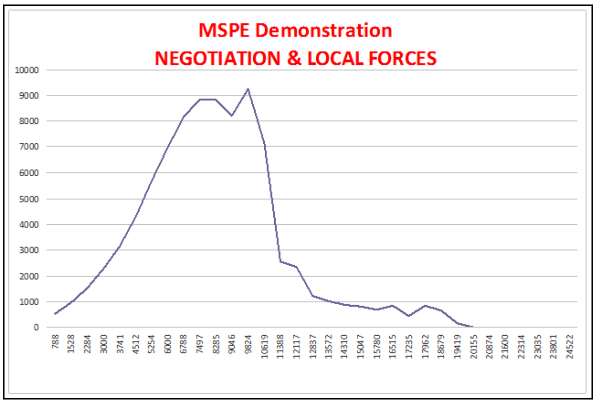

Fig.19: Option 3 - Negotiation & Local Forces - Number of Demonstration MSpE

In following figures multiple runs are compared for the different evolution of this scenario; different end states could be approached during the simulation due to stochastic components therefore final achievements results consistent based on MSpE.
A further analysis has been conducted by measuring the Number of demonstrators during the simulation considering the four different possible Commander decision respect the main COA to be adopted during the game. The result of the MSpE considering 10 replicated runs is proposed into the attached figures.
By applying Design of Experiments it was completed a set of experimental tests for evaluating the influence of the independent variables respect the target functions; this Sensitivity Analysis is synthesized in last figures 20a and 20b where the main alternative COAs are compared respect target function.
SIMCJOH_VIS was extensively tested federated with SIMCJOH_VIC and with other HLA Federates within SIMCJOH Federation including among the others: GESI, SGA, SC and its overall target functions are proposed in terms of temporal as reported (see fig 7)

CONCLUSION

SIMCJOH_VIS (Interoperable Virtual Simulator) represents an important opportunity to create new dynamic scenarios for different applications: preparation and briefings related to new environmental conditions (immersion in new scenarios), training on the comprehensive approach, training, etc.

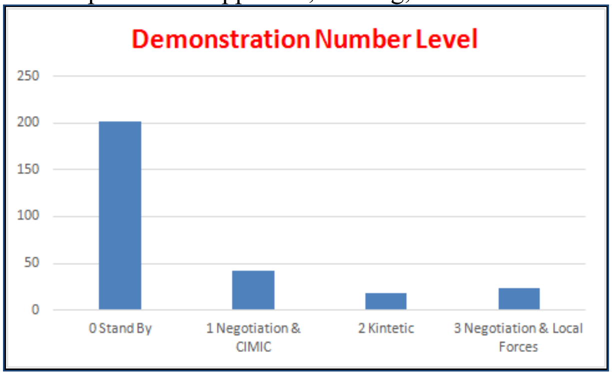

Fig.20a: Sensitivity of the Main Decision on Demonstration Average Size

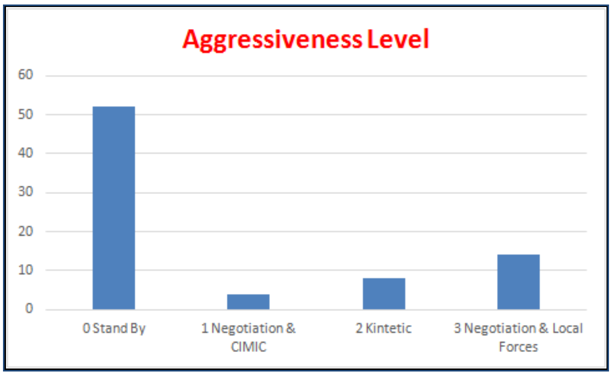

Fig.20b: Sensitivity of the Main Decision on Aggressiveness Level

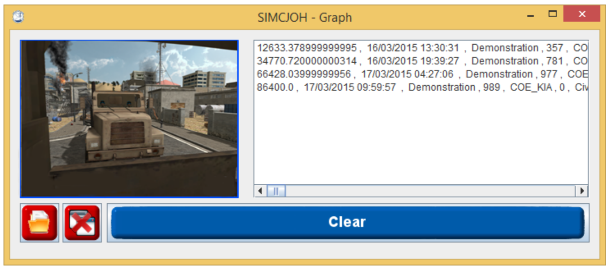

Fig. 21: Target Function Report

The human models of SIMCJOH_VIS could be integrated with other scenarios, missions and operations where these aspects are important and may interact with other models and simulators. In fact the SIMCHJOH_VIS is built for validating and experiencing the potential of a new generation of MS2G (modeling, simulation interoperable and Serious Games) able to use human behavioral patterns (HBM) and ensure interoperability with other simulators to recreate complex scenarios. Indeed SIMCJOH_VIS is also further developable to create a system for training able to reproduce case studies and to provide an interactive environment to understand reactions and human factors related to decisions and events. The authors re currently working to develop new actions and mission environments based on this approach and are planning to use SIMCJOH within existing CAX

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DISTRIBUTED VIRTUAL SIMULATION SUPPORTING DEFENSE AGAINST TERRORISM

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ABSTRACT

This paper propose an innovative MS2G (Modeling, interoperable Simulation and Serious Game) to address Defense Anti Terrorism (DAT) the solution proposed allows to access to a web application adopting SaaS (Simulation as a Service) paradigm over secure networks for experimenting and or exercising on this context. The possibility to investigate specific scenarios changing boundary conditions as well as hypothesis allows evaluating most effective actions for vulnerability reduction versus potential terrorist attacks. The use of intelligent agents allows executing automatically the scenario based on dynamically aggressive and defensive interactions; the proposed models present a virtual representation that immerse the user in an easy understandable framework supporting crowdsourcing among subject matter experts on DAT.

Keywords: *Defense Anti Terrorism, Intelligent Agents, Simulation, Crowdsourcing*

INTRODUCTION

Last fifteen years the terrorism represented one of the major issues for the Nations and the current situation is not really promising about the future; in facts actions from isolated groups fighting against authorities and government were extensively present along the last century (Hudson et al. 1999; Endes et al. 2002).
Therefore it is evident that the technology developments in several sectors increased the impact of the attacks as well as the vulnerability of the Nations. The evolution and diffusion of innovative communications, media and social networks further emphasized the impact of these elements (Matusitz 2013).
After the twin tower attack many Nations and International Organizations activated new research programs addressing terrorism that further evolved along last decade (Benney et al. 2009).

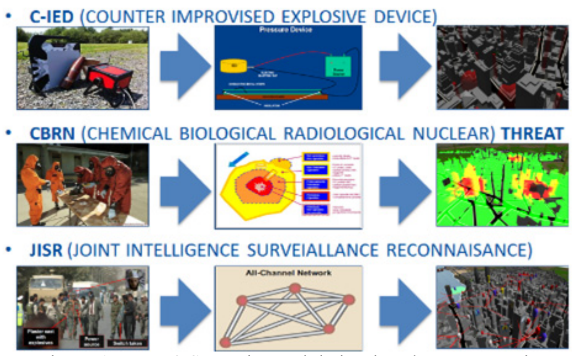

Figure 1 – DVx2 Scenarios and their Virtual Representation

In particular NATO established in 2004 the NATO DAT PoW (Defense Against Terrorism Program of Work) developing innovative solutions on different areas to face these threats; this paper proposes the development of innovative simulation solution based on MS2G (Modeling, interoperable Simulation and Serious Game) to address the complex sector of defense against terrorism and it was developed under NATO DAT PoW (Bruzzone et al.2014a); in addition the authors developed this simulator based on SaaS Paradigm (Simulation as a Service) in order to make it available over the web as a cloud service.
The main goal of this project was to evaluate vulnerability reduction versus terrorism in reference to the achievements of the NATO research on the area along last years (Bruzzone, Tremori 2014b).

1. DAT APPLICATION FIELD AND SIMULATION

The DAT operational requirements and shortfalls has been addressed within 11 items in the DAT PoW instantiated by the Conference of National Armaments Directors (CNAD 2004 and following):

- Large-Body Aircraft Against Man-Portable Air Defense Systems (MANPADS)
- Protection of Harbors and Ports (HPP)

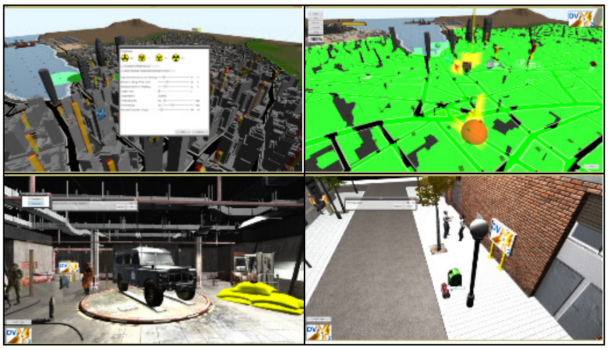

Figure 2 – DVx2 Virtual Representation of Scenario Parameters, Damages due to multiple attacks, Countermeasures Setting and *Hot Spot* on Attack Site (left up to right down)

- Protection of Helicopters from Rocket-Propelled Grenades RPGs
- Counter Improvised Explosive Devices (C-IEDs)
- Explosive Ordnance Disposal (EOD) and Consequence Management
- Precision Air-Drop Technology for Special Operation Forces, Detection
- Protection and Defeat of CBRN Weapons
- Technology for Intelligence, Surveillance, Reconnaissance and Target Acquisition (ISRTA)
- Defense against Mortar Attacks (DAMA)
- Protection of Critical Infrastructure (CIP)
- Non-Lethal Capabilities (NLC)

Simulation was identified as a solution for demonstrating and presenting virtually the achievements of the related researches carried out on this area along last 10 years; indeed an important benefit arising from using simulation is the possibility to provide subject matter experts (SME) with an interactive tool allowing to conduct experiments (Longo 2010; Longo 2012);

This capability becomes even more significant in case the innovative MS2G paradigm is applied, because the SME could access remotely the simulator and share not only results, but also hypotheses and scenario configuration to compare their assumptions and mutually validate their conclusions (Bruzzone et al.2014a).

This aspect for DAT is very important considering the complexity of the scenario, but also the heavy uncertainty over many factors; in facts, in terrorism, it is pretty difficult to have reliable statistics on attack probabilities, efficiency and effectiveness of attacks and defensive solutions (McKercher et al.2004).; this is not only due to the security issues, but even to the continuous evolving nature of these aspects that reduce the size of available samples as well as the possibility to conduct valid live experiments.

In 2002 there was a panel on M&S organized by MIMOS (Movimento Italiano Modellazione e Simulazione) where it was proposed the question about "*how simulation could support anti-terrorism considering the inventive and creativity of human beings in preparing attacks*" (MIMOS 2002); in such occasion Prof. Bruzzone stated that "*while it is impossible to predict terrorist attacks, it could be pretty feasible to simulate them, obviously not to support terrorist plans, but to evaluate vulnerability reduction achievable by alternative solution*".

This paper proposes DVx2 simulation that addresses exactly these issues after several years with benefits from currently available technologies and new methodologies (e.g. SaaS, MS2G).

Indeed simulation aims to create a consolidated benchmark for vulnerability reduction and accomplishment, based on the assessments made by experts. Considering the complexity and dimension of DAT it was obviously necessary to define bounds for the model development, indeed the authors decided to start the modelling working on three important elements of the above presented list: C-IED/EOD, CBRN, JISR (Bossomaier 2000; Bossomaier et al. 2009).

In facts simulation could be used to address multiple aspects from capability assessment to training; therefore a major innovative aspect, in this case, is the use of the MS2G for creating a distributed framework that could support crowdsourcing (Bruzzone et al. 2014a); in anti-terrorism crowdsourcing is a major issue devoted to allow the Subject Matter Experts to interact each other and to share estimations, ideas and solutions; it is evident the possibilities enabled by providing an interactive simulation environment that could be used over secure networks for this purpose; another aspect not to be neglected is the possibility to use these models for exploitation of the results among decision makers or general public; obviously all these issues should deal with the sensitive nature of some of the research and this paper address just public releasable information related to the conceptual modelling of the initiative.

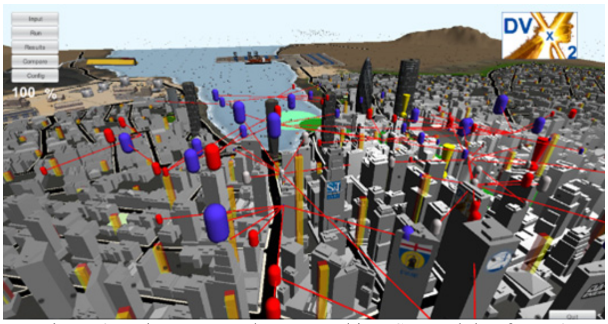

Figure 3 – Threat network presented in JISR module of DVx2

2. SIMULATION AND CROWDSOURCING AGAINST TERRORISM

The idea to create simulation models for anti terrorism (and even for conflicts management) has been investigated since many years and resulted pretty popular since September 11 (Mosca et al. 1996; Smith 2002; Petrova and Camponeschi 2002; Abrahams 2005; Oren and Longo, 2008; Bruzzone et al.2009a, 2009b).

In this case some the authors propose the use of simulation within an innovative paradigm corresponding to M2SG (Bruzzone et al. 2014a).
The authors developed the proposed simulator DVx2 (Distributed Virtual eXperience and eXercise) within specific areas (e.g. Counter Improvised Explosive Devices, CBRN, JISR) to address the DAT complexity by a modular approach as proposed in figure 1.
Indeed DVx2 simulator has been developed with the goal to collect knowledge and experience from anti-terrorism SME by applying the MS2G; the simulator combines interoperable simulation and web serious games to create a distributed environment where simulation could be delivered as a service. A major advantage in this case is based on the use of IA-CGF (Intelligent Agent Computer Generated Forces), developed by Simulation Team, for directing terrorists and defenders (Bruzzone et al.2011a, 2011b).

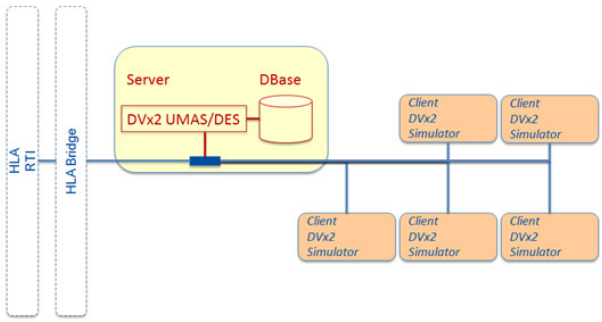

Figure 4 – DVx2 Architecture

The agents allows to carry out several runs automatically extending the experimentation capabilities of the simulator; so by this approach the SMEs could use DVx2 to test the effect of independent variables and assumption on the vulnerability reduction; DVx2 is pretty efficient currently so it is possible to conduct these experimentations interactively by investigating several configurations and analyzing immediately the results in the virtual environment.
DVx2 presents the situation in terms of 3D visualization of the town at high level as well as the distribution of damages, casualties, evacuation areas (see figure 2); all these parameters evolve dynamically during the run to allow understanding of the events, therefore in usual experimentation due to the high ratio fast time simulation this could be not appreciated. Special 3D detailed scene are generated to reproduce *hot spots* used for proposing the SME attack sites and/or possibility to change the parameters by clicking on virtual objects.
Indeed simulation results in terms of scenario configuration, risk analysis and key performance indexes about vulnerability reduction are stored in the cloud; this database allows the creation an up-to-date knowledge reference respect DAT that is populated by dynamic experimentation of SME over multiple scenarios. Indeed the DVx2 synthetic environment is currently focused on specific issues related to C-IED (Counter Improvised Explosive Devices), JISR (Joint Intelligence, Surveillance and Reconnaissance) and CBRN (chemical, biological, radiological, nuclear);.
Mixed scenario could be developed combining the different aspects indeed DVx2 uses IA-CGF to simulate dynamically the evolution of the threat network as proposed in figure 3.
DVx2 has been developed to address just some specific elements of these DAT PoW however it is evident that interoperability approach to the modeling allows to add other simulators or meta-models to extend its validity to new areas or to modulate its resolution and details towards specific elements (Kuhl et al.1999).
Within the specific case addressed the DVx2 allows the users to set parameters and to finalize decisions, while the simulator evaluates risks and impacts in term of vulnerability reduction. The DVx2 virtual world is used also to propose final results within an effective representation and allowing players to understand at glance the results of the simulation. DVx2 is implemented as web based serious game able to operate over secure networks; it was also investigated the possibility to activate a special release for NATO users on DBNL (Distributed Networked Battle Labs) for technological tests, therefore DBNL not classified network current planning reduced the priority of this initiative (Siegfried et al. 2014). It is important to outline that DVx2 conceptual model was developed considering High Level Architecture (HLA) as reference interoperability standards for future extensions and reuse as a distributed federate within large federation of simulators (Bruzzone et al.2011).
In addition, through a proper authorization scheme and access levels, the users could access the DVx2 Dbase and compare dynamically their experiments with others carried out by colleagues based on different assumptions; this allows to understand how much conservative or optimistic are their hypothesis as well as to evaluate the efficiency and effectiveness of the different alternatives on the simulated scenarios.
In this way DVx2 turns into a very effective support for Crowdsourcing and for interactive distributed experimentation; obviously the simulator has also a great potential as tool to be used for education and training (Tremori et al.2012); indeed use of simulation could support the development of virtual distributed exercise (Raybourn 2012)
So the use of MS2G in this context is expected to provide a consolidated approach and benchmark for new DAT capability; DVx2 could evaluate the accomplishments of DAT initiatives in terms of vulnerability reduction, for future planning and recognition of accomplishments, while the distributed nature of this approach allows to empowering SME networks.
The DVx2 general structure and architecture is based on the combination of stochastic discrete event simulation with Intelligent Agents playing the role of terrorists as well as that one of the DAT resources (Hill 1996; Banks 1998; Bruzzone et al. 2011b). DVx2 user accesses to this simulation service and he is enabled to define the

actions, assets, policies; he could select the hypotheses to be adopted in relation to the different DAT scenarios.
The Intelligent Agent Computer Generated Forces direct the terrorist actions and countermeasures during the whole simulation and by simulation are measured evolution risks as well as the vulnerability reduction (Bruzzone et al. 2011a); indeed the simulator estimates damages, costs as well as casualties and allows comparing different alternatives and/or estimations by SME.
DVx2 addressed VV&A (Verification, Validation and Accreditation) by informal techniques and dynamic experimentation; indeed the approach for development and validation is based on lean simulation concept (Bruzzone, Saetta 2002). In facts the validation of the correctness of the conceptual models respect the Simuland (the framework simulated by our computer models) should be checked by engaging simulation experts in the review process (Balci et al.1996; McLeod 1982); in addition it is necessary to verify the consistent implementation of the software code respect the conceptual models (Balci et al.2011). From this point of view the SME and CMRE Simulation Experts conducted face validation and dynamic test on DVx2 in order to address these issues (Amico et a. 2000);.
The DVx2 Architecture is based on Simulation as a Service Architecture that enables users to experience the DVx2 serious game directly on the web via a web browser by downloading a plug in (Guo, Bai, Xu 2011; Tsai et al.2011); this solution results flexible respect the Operating System in use. To guarantee full access to all potential users a stand-alone version to run locally or within a web browser framework was developed to test the GUI (Graphic User Interface) as well as the simulation engine and also for use from workstations that are operating within secure networks with heavy restrictions on internet access.
For these purposes the architecture includes conceptual element such as DVx2 User Management and Access System (UMAS) and the DVx2 Discrete Event Simulator (DES) as proposed in figure 4.
The DVx2 UMAS should be devoted to provide game users as well as game administrators with an easy to use system to create and manage users' accounts. The DVx2 UMAS was initially developed by using PHP while the main database used to store data (both user data as well as simulation input/output data) were implemented by using MySQL. As first step, two main roles were created as part of the DVx2 UMAS: the Administrator User and the Player User.
The DVx2 DES is a simulator (written in JAVA programming language) that takes care of the game evolution according to a stochastic discrete event simulation that depends on the variables and parameters set-up (made by the player users at Client level).
Finally the DVx2 architecture could also include an external bridge to IEEE 1516 HLA federation of simulators. This part of the architecture is devoted to guarantee the possibility (for future developments) to connect the DVx2 serious game as a federate of an HLA federation of simulators; the HLA Bridge was not integrated in the current release.
By this approach the DVx2 users compare the results achieved by changing parameters and by adopting different hypotheses working distributed over the web; this approach allows to investigate large set of alternatives through an interactive approach enabling crowdsourcing (Bruzzone et al. 2012; Elfrey 2006).
In terms of implementation the decision to enable use of Virtual World over the web through a browser introduced some computational efficiency constraint as well as aspects related to band availability; so during the development of DVx2 emerged the importance to provide the user with interactive and effective control of the virtual representation to represent the results. Due to the high volume of data the final structure of DVx2 was forced to consider the requirements to operate on the web and to be more interactive, so several models were moved from DVx2 DES to the original DVx2 GUI that evolved into a real simulator as proposed in the following structure that represent the final architecture proposed for the simulation.
This solution is effective in case of multiple SMEs running independent simulators, while in case of multiplayer interactive simulations this approach requires to enhance the DVx2 DES to enable this capability; in the DVx2 current release, the different users are enable to run multiple scenarios in competition, for instance as replication for testing reliability versus stochastic factors and for measuring resilience and robustness as well as for changing assumptions and parameters, therefore the intelligent agents play each run separately and the comparison is just on initial and final results.
DVx2 supports the processes and game logic depicted in figure 5; obviously in stand-alone respect crowdsourcing DVx2 is addressing just the simulation part, avoiding to take care of profile management and Dbase integration.

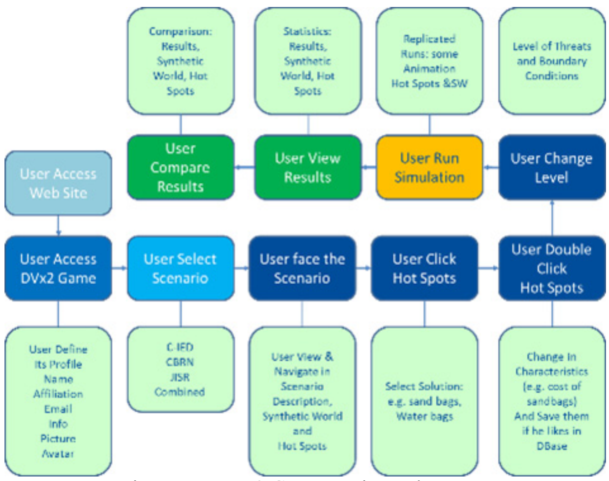

Figure 5 – DVx2 Game Logics and Process

In the current implemented release of DVx2, the user accesses to the DVx2 environment by selecting the game alternatives and then he proceeds in preparing and analyzing the simulation runs; these activities are carried out within the DVx2 virtual framework while the results are proposed both in numerical and graphical forms.

DVx2 implements different target functions that allows providing an interactive assessment of impact of the DAT PoW achievements in terms of vulnerability reduction; in such sense the use of simulation allows to estimate a large spectrum of target variables able to provide a complete picture of the vulnerabilities respects many alternatives. Therefore for crowdsourcing just main variables are available in the Virtual 3D GUI for the user in order not to confuse him with too many factors. For instance in this case among parameters estimated by the simulator it was possible to collect: Casualties, wounded people, Reaction Time, Suspicious /Cleaned Area, Evacuation Time, Total Evacuation Costs, Success Rate, Correct Evacuation Range.

DVx2 demonstration success leads forward to the opportunity to use it for experiments devoted to reinforce its validity and create accreditation among SME community; indeed it is valuable to conduct experiments to measure the effectiveness by working with experts; indeed it is a strategic advantage to have access to a simulation framework that enable the capability to share and evaluate crucial interactive experimentation over DAT scenarios the community of expert for creating a dynamic repository of the related knowledge.

CONCLUSIONS

The new proposed approach based on MS2G is enabling crowdsourcing and data mining through combined use of M&S, IA and SG, so it becomes possible to involve a large number of people to keep up-to-date their know-how through interactive and engaging serious games.

This allows collecting data and information that are used to populate databases useful to better understand the different expert hypotheses as well as related to consequences estimated by the simulation. The authors focused this analysis on specific areas of DAT PoW and the related scenarios were useful to test the concepts as well as to investigate how M&S, IA, SG and immersive technologies could be effective in this environment.

An important follow up guaranteed by MS2G approach is the capability to create an interactive distributed simulation that could be effective for being used for training, education, dissemination, capability assessment, testing and experimentation by different users; for instance in DVx2 has an interesting potential in terms of general purpose for being applied in training and education for both over military and civil personnel, as well as for the diffusion of NATO DAT PoW Achievements.

A major benefits of DVx2 is the possibility to Support to Development of New Concepts and Solutions by Virtual Interoperable Testing; in similar way DVx2 could be used for the development of New Capabilities for Strategic Scenario Evaluation by New Simulation Models

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GUIDELINES FOR DEVELOPING INTEROPERABLE SIMULATION FOCUSED ON MARITIME OPERATIONS COMBINING AUTONOMOUS SYSTEMS AND TRADITIONAL ASSETS

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ABSTRACT

The main aim of this research is to identify the opportunities and potential for using M&S in addressing the use of autonomous systems to augment maritime capabilities by interacting with traditional assets.. This subject, in this case, is applied on Autonomous systems competing and collaborating with other elements operating over different other domains; the paper address identifies interests, available models and resources as lead to define guidelines and references to create an interoperable simulation framework for training and tactical decision aid.

Keywords: *Autonomous Systems, Interoperability, Modelling and Simulation, Joint Naval Training, Tactical Decision Aid*

INTRODUCTION

The use of simulation is becoming more and more important in many sectors; in particular defense is experiencing revolutionary results in terms of training efficiency and effectiveness through simulation since decades.
The need to combine different models to recreate complex scenarios is a major issue and the possibility to integrate real systems in the simulation is fundamental both for training and for decision making.
Due to these reasons it emerged a need to create simulators as mosaic where the different elements where tiles to be combined based on a conceptual and technological interoperability.
Obviously initially the main problem was about technology and refurbishment of existing simulators to interoperate; therefore these aspects evolved quickly and thanks to Institutional support over passed the classical "stiction" characterizing the introduction of new technological solutions.
These aspects moved up the priority to create models and simulators able to populate libraries for developing complex scenarios; the problem in this case is more deep than just technological, dealing with commercial, IPR, conceptual modelling, security and resolution issues. Therefore it is evident today the potential to create such new interoperable simulation environments by using the models developed in these year as well as the innovative methodologies; all these factors enable the creation of new federations and to properly cover complex scenario by giving access to data, models and resources.
Considering the evolution of the military operations and assets this potential becomes even more strategic, allowing to investigate new procedures, policies, technological solutions over the new mission environments.
Obviously the fast evolving use of autonomous systems is one major driver on this aspect; indeed often it is necessary to develop from the scratches the doctrines and utilization modes, as well as to invent the requirements of the new systems; simulation is probably the only proper solution to address these issues.

Among the critical scenarios the authors propose here the naval operations within maritime extended framework (including multi domains such as underwater, surface, coast, air, space and cyber space); in this case as in other context, the use of autonomous systems is supposed to proceed gradually being integrated with existing platforms and systems.
It is evident the need to develop training and decision support aid based on simulation able to deal with this complex case that is strongly relying on interoperability issues. The author propose here a research carried out in order to evaluate the available resources as well as the potential to further proceed in this direction within a naval scenario involving of autonomous systems competing and collaborating each other and with traditional assets over different other domains.

1. INTEROPERABLE SIMULATION

Indeed the introduction of interoperable simulation further empowered the use of M&S (Modeling and Simulation) even if many actors limited the full achievement of its potential along the last twenty years. Adoption of HLA, as revolution respect DIS concepts within few years along the middle of '90, was really a great achievement; therefore it was not an easy deal for this concept to succeed, and it survived to the industrial inertia and commercial issues mostly based on the US DoD will power and the good will of wise Scientists and technicians from Academia and Industry. The complexity of applying new conceptual design criteria based on distributed object oriented approach resulted not trivial for the developers; this aspects was further reinforced by the necessity to adapt these concepts to legacy systems evolving from obsolete technologies and old architectures. The simulation community applied extensive efforts along these twenty years to support development of skills and background knowledge in the area by many initiatives such as (McLeod / M&S Net Certification program, CMSP, Smackdown Initiative, Simulation Exploratory Experience, Body of Knowledge and HLA Outreach Program) still representing very important achievements and strongholds (McGlynn 1996; McLeod 1999; Amico et al. 2000; Morse 2000; Waite 2001; Ören & Waite 2007; Bruzzone et al.2009; Elfrey 2011).
Therefore the diffusion of HLA and the extensive application of interoperable simulation was even limited by IPR (intellectual proprietary rights) not only on the models and simulators, but mostly on the real systems to be integrated in such interoperable federations (Mevassvik et al. 2001; Huiskamp 2007, Strassburger et al.2008); indeed in most of the case the real systems were expensive industrial products of defense industry. In several country protective actions were also applied to limit the diffusion of the new standards respect the use of previous ones where background knowledge a products were already developed (Boer et al. 2008); so the HLA adoption by NATO as reference guideline in late '90 and its formal recognition as IEEE Standard was promoting it further, therefore its diffusion was not so capillary as it could be expected originally for the above mentioned reasons. Along the years some other approaches for interoperable simulation were proposed, achieving very limited diffusion, often limited to single groups; their reasons for failure included previous issues; but in addition the related results provided often questionable achievements in terms of performance and reliability, plus strong limitations in replicability, and in addition these proposals were missing the effect of DoD actions and were lacking promotion from effective international scientific community (Martínez-Salio et al 2012). So despite we are going to celebrate 20 years of HLA this architecture still the main references for M&S interoperability and guarantees a big potential for further developments by being integrated in modern technologies and innovative approaches (NATO 2009, 2009, 2012). Indeed it is important to outline that HLA is not a technology, but corresponds mostly to an architectural and conceptual approach to distributed interoperable simulation, while its implementation into the RTI (Run Time Infrastructure) is achieving significant improvements over the years through very good commercial products (e.g. Pitch & MÄk) and qualified open source solutions (e.g. Portico).
Due to these reasons it becomes pretty interesting to develop HLA framework for creating new simulation frameworks integrating models and simulators based on innovative technologies. As far as the maritime environment is concerned there are already examples of interoperable simulators used for different purposes including education, training and decision support both on the sea-side (e.g. Longo et al. 2013; Longo et al., 2014) and on the land-side (Bruzzone et al. 2011; Longo, 2010; Longo 2012). Therefore, it is even more evident the possibility to use interoperable simulation to augment the "maritime capabilities" combining autonomous systems and traditional assets. To this end, the main aim of this research is to define guidelines and references models for the creation of such interoperable simulation.

2. SIMULATION TO AUGMENT MARITIME CAPABILITIES

Currently surface ship, underwater vessels and naval air components rely on many sensors including sonar, radar and E/O systems to detect, localize and classify potential threats; even in these day the introduction of autonomous systems (e.g. UAV Unmanned Aerial Vehicles) is leading to the creation of a dynamically evolving sensor network integrated with other assets.
Future scenario are expected to deal with many autonomous systems operating in multiple devices as resources for the opposite actors, so creating a competing and collaborative environment integrated with traditional assets and resources as proposed in figure 1.

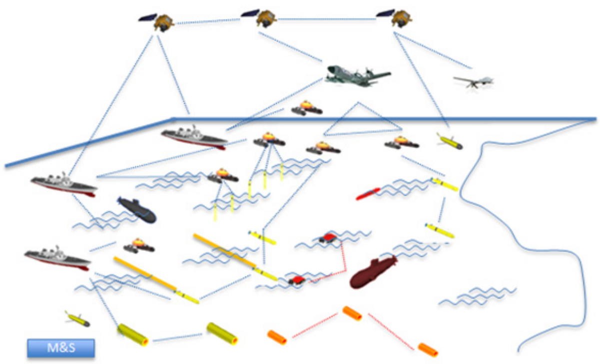

Figure 1 – Example of Possible Future Scenario

Therefore in future we expect that these aspects further evolve by a more intense use of the autonomous systems into operational issues and requiring them to cooperate on complex tasks while operating within different domains.
It is interesting to address the specific aspects related to the ASW (antisubmarine warfare) or MCM (Mine Countermeasures) operations where the complexity of the detection stresses further the need to collaborate over the different domains to augment the capabilities; in this context vessels and sensor infrastructures, helicopters and planes are extensively used and even integrated by innovative AUV (Autonomous Underwater Vehicles). For instance in ASW, the tactical data links provide multiple ships and aircrafts with a means to augment their overall search and classification rates, while multi static approach in active sonar represent a new capability for improvement active search based on interoperable sonar networks including decoupled sources and receivers .
These overall capability improvement result possible by the complementarities of search and prosecution tempos between air and sea surface combatants.

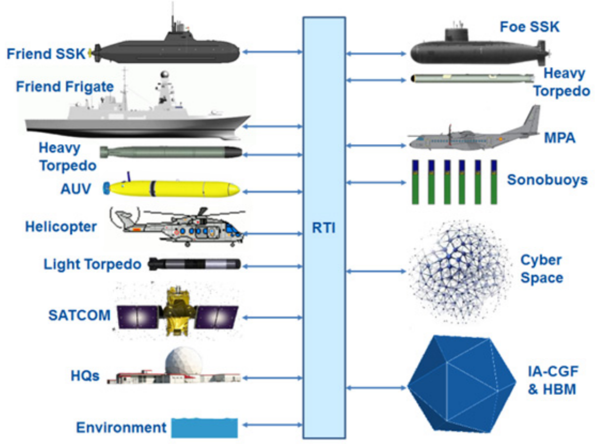

Figure 2 – Example of Federation for Demonstrating the proposed Concepts

The introduction of unmanned maritime systems still affected by heavy limitations in terms of autonomy, range of operation, speed and payload, promote the investigation on how to employ and design them; For instance it becomes important to identify most relevant requirements and most sensitive variables for current and next generation of autonomous systems: e.g. many small light devices or few heavy ones?
It is also very crucial to develop the procedures and policies for using these assets and to combine them within the traditional assets to improve the maritime capabilities.
For instance USVs (Unmanned Surface Vessels) are usually subject to sea limitations while UUVs (Unmanned Underwater Vehicles) are limited in terms of speed, payload, communication capabilities and endurance and Naval UAV still need to improve their capabilities in operating safely from surface vessels. Moreover, all the autonomous systems had to deal with their limits in terms of on-board intelligence and communication throughput.
This last issue suggests the need to develop ad hoc strategies for commanding and controlling them respect just to consider such autonomous assets equivalent to man operated devices; so man-on-the-loop, as high level supervision with task assignment emerge as an additional aspect to be investigate (Magrassi 2013).
Indeed numerous studies and demonstrations on specific systems have been conducted confirming concluded that autonomous systems have some potential to improve effectiveness and efficiency in naval missions (Jans et al. 2006; Been et al. 2007, 2008; Wathelet et al. 2008; Caiti et al. 2011; Strode et al. 2012; Santos et al.2013; Carrera et al. 2014); therefore these analysis were mostly based on mission scenarios or concepts of use strongly related to general assumptions referring to surface ship and/or MPA contributions.
Indeed the goal of this study is to better quantify the benefits of unmanned systems when they are inserted into naval joint operations and interact with traditional assets over multi domains.

3. ELEMENT OF THE FEDERATION

The critical issues to be addressed to face these challenge include several aspect.
A major element is to identify the legacy systems available in the different Nations and Research centers; these include different kind of models and simulators.

***Mission Environments and Behavioral Model*s:**
These includes simulators of standard naval missions, search models and algorithms, classification tactics, threat behavioral models for current and future scenarios

Traditional Assets and Platform Models
Models of Surface Vessels and their assets (e.g. helicopter, UAV, AUV), Models of MPAs (Maritime Patrol Aircrafts), Models of Submarines, Models of weapon systems etc.

Sensor Models
Models of different kind of sensors (e.g. radar, EMC, active mono static sonar, multi static sonar, passive sonar, towed arrays, magnetic anomaly detector).

Autonomous System Models
Models of UUV, USV, UAV, AUV and of their capabilities (e.g. communication, payload, movement and autonomy, internal intelligence)

Environmental Models
Models representing the environment and related modifiers on sensor and platform performance (e.g. sea, current, fog, waves, salinity, temperature, thermal layers.)

Command and Control Models
Models about the characteristics and architecture of the C2 and tactical data links (above and under the surface) including rules routing and elaborating data and responsibilities to take decision.

Measure of Merits
Development of models able to quantify over the simulation the performance and the achievement of success over different aspects (e.g. readiness, target accuracy, reliability, cost).

An example of general scheme of the federation to be used for such development is proposed in figure 2 considering a sub set of elements and objects to be federated.

4. ROADMAP FOR DEVELOPMENT

Based on recent survey the proposed topics result interesting for several Nation that is supposed to drive the general roadmap of this activity (Bruzzone 2014).

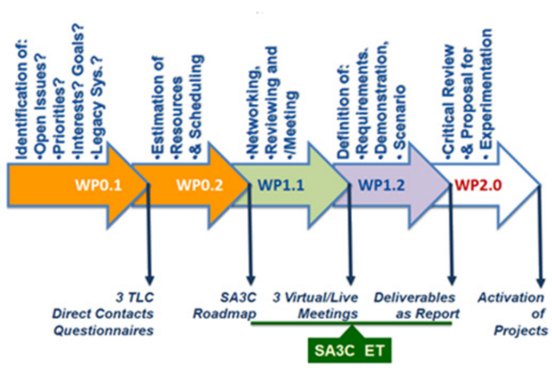

Figure 3 – SA3C High Level Roadmap

Indeed the investigation of multi domain autonomous systems as well as ASW, Port Protection and MCM operations and the related simulation models results very important. The interoperability among the autonomous systems is considered a priority for many stakeholders respect the study of the single system (Massei et al.2013).
The authors identified HLA as the architecture to be used for creating an federation to be used for experimenting the potential of this approach and for providing preliminary results.
Based on preliminary survey different sonar models and engines environmental model, tactical simulators and behavioral models are already available for being integrated in the proposed architecture.
The list of the module under considerations for being federated include scenario generators, C2, IA-CGF (Intelligent Agent Computer Generated Forces), COS Surrogates, AIS Simulators, Maritime Virtual Simulators, Ocean Models, Bottom Reflection and Acoustic Models, Navigation Simulators and a Marine Cyber warfare Simulator.
A major issue to proceed in this research will be to engage operational and technical people as well as scientists over different nations and it is interesting to outline that NATO is already promoting an Exploratory Team dealing with this initiative (NMSG ET-036 SA3C "modeling and Simulation of Autonomous ASW capable vehicles to Augment surface and maritime air Capabilities") and a general roadmap is proposed in figure 3.
Therefore it is evident due to the nature of the case study the sensitivity of most of the data and model, introducing the necessity to properly deal with the security issues during the experimentation; this introduces a major problem for the development of this research; therefore the authors are planning to create a "realistic", but not sensitive, framework based on public domain model could be extensively used to demonstrate the proposed concepts. Indeed the NATO initiative is currently devoted to demonstrate these M&S capabilities, keeping the scenario at lowest possible level of classification and to leave it as an open resource for further investigation by the Nations; indeed this initiative is devoted to create and demonstrate a capability for the future, so there aren't particular constraints for classified simulation in it and this could also reduce impact of these issues on the project coordination and development.
Obviously doctrines, ROE (rules of engagements) and behavioral models as well as asset simulator in this case will be substituted by other models different from real ones and/or meta-models; therefore considering the adoption of a flexible interoperable approach, these elements could be easily substituted with high fidelity federates by the stakeholders for their investigation outside of the proposed experimentation.
In facts it is evident the necessity to develop behavioral elements to be federated into the HLA framework for the proposed demonstration; based on this concepts it becomes evident the necessity to integrate specific models able to deal with the onboard intelligence of the autonomous systems and able to reproduces their situational awareness and collaboration capabilities (Bruzzone et al. 2011b; Bruzzone et al.2013b). These

aspects normally deal with the autonomous system capacity to communicate in real time, or with a certain delay, as part of a dynamic heterogeneous network; this outline the importance to include models of these ICT network and communication aspects reproducing cyberspace (Bruzzone et al.2013a).

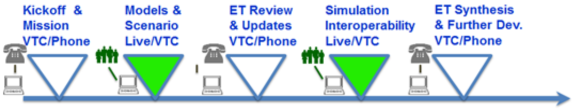

Figure 4 – SME and Stakeholder Engagement Plan

In addition to these elements it is important to outline that the C2 systems in this context are often multi level, including single ship, Nation, Coalition, Multi Coalitions operating within the same framework; these aspects require to create models of multiplatform data/contact/track fusion and to simulate multiple concurrent decision processes regulated by the evolving boundary conditions (Bruzzone et al. 2011a).
Despite the research deals with using autonomous systems, it is fundamental to remember that most of the active assets are man operated and their decision making procedure as well as the related human behavioral models (HBM) are crucial element in scenario evolution; this is further evident if this concept is stressed by outlining the importance to model the vessel crew as key element of such weapon systems (Bruzzone 2013c); indeed simulations of human behavior modifiers including rational and emotional elements, workload capabilities, hierarchical autonomy should be consider in the model as critical element further reinforced by conditions of potentially severely limited communications.
Another important aspects include the capability to combine other elements such as cyberwarfare or maritime air E/O, MAD as part of this simulation.
In general the success of this initiative is strongly related with the capability to guarantee SME (Subject Matter Expert) and stakeholder engagement through Verification, Validation and Accreditation (Bruzzone 2002).
The authors are currently promoting this aspect considering the following elements to be part of such interaction:

- Survey on Resources and Capabilities
- Identification of Additional Potential SME/Stakeholders

Contributing on:

- Definition of SA3C Architecture
- Selection of Federates and Models
- Interoperability Architecture
- Scenario Definition

Stakeholders should be part of the Analysis of potential resources and capabilities in order to proper Select/Develop Models, Federates and Federation Architecture

The Stakeholders should contribute to define the Scenario devoted to address main expectations, operational relevance, requirements for available resources and new assets and investigation on alternative solutions.

CONCLUSIONS

Interoperable Simulation for addressing Joint Naval Opertions with specific attention to training and decision support is characterized by different main streams in term of potential:

- Empowerment of legacy systems and internal Activities by enabling Interoperability and Distributed Simulation Capabilities
- Support to Development of New Concepts and Solutions by Virtual Interoperable Testing
- Development of New Capabilities for Strategic Scenario Evaluation by New Simulation Models

Each of these elements represents a great opportunity to enhance the maritime capability through extensive use of interoperable simulation; in the future their synergy could guarantee the possibility to create a new framework for the M&S Community operating over the multiple domains affecting this mission environment. It is evident that these concepts could be easily extended to other scenarios and other problems. In addition the oil and gas off-shore operations represent a very promising opportunity for dual use of these models in surveillance and support to the underwater operations as well as for safety and security procedures.

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