Using Simulation Based Training Methods for Improved Warfighter Decision Making

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Abstract. Few efforts have greater significance to our warfighting capability than those aimed at dramatically improving the skills, knowledge, and experience of military decision makers. The research and technology ideas presented in this paper are motivated by need to improve the quality of decision makers through the design of innovative training technology for military decision makers. This paper describes an adaptive simulation based training approach to improve the effectiveness of warfighter decision making. The paper describes (i) a method for adaptive simulation based training; (ii) a mission-driven approach to measure trainee performance based on carefully designed metrics; and (iii) an automation support architecture for adaptive simulation based training. Examples are provided throughout the paper to illustrate key research ideas.

Keywords: Simulation Based Training, Warfighter Decision Making, Adaptive Training, Mission Driven Performance Measurement.

1 Motivations

This section summarizes important technology gaps in the area of simulation-based training to enhance warfighter decision making effectiveness. The central problem is the inability to rapidly refine and adapt simulation based training content to address focused training needs. Currently, simulation based training content is painstakingly handcrafted by subject matter experts (SMEs) and this content is not maintained in a manner that facilitates rapid change. Moreover, simulation based training systems do not provide mechanisms for automatically determining training content changes based on the analysis of measured student performance. Current simulation-based training systems lack the ability to efficiently adapt the current state of a scenario to a desired state that will address the training goals. Consider the simulation-based Military Operations on Urban Training (MOUT) infantry training exercise in which the goal is to detect and eliminate a sniper. If, during the training, the trainee constructs a smoke-screen or exits his vantage point, these actions serve to render the scenario ineffective for the intended goal. To use another example, in an air combat exercise focused on increasing threat awareness in the presence of enemy radar sites, the trainee's departure from the radar site area renders the scenario ineffective for the

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exercise's "increase threat awareness" goals. Under current simulation-based training systems, the instructor would have to issue a request to the simulator operator in order to create a set of new Computer Generated Forces (CGFs) for the trainee in order to meet the goals of the exercise. Such a request has an unacceptable response time, especially towards the end of the exercise. It is often the case that the instructor defers the unfulfilled training goal to a future simulation exercise. This carries the risk that the same course of events would ensue even in future exercises. Adaptive simulation content generation methods may be used to automate the generation of new training drills and scenarios within seconds of sub-optimal trainee actions. In the first example, a new CGF action (a simulation 'drill') will be automatically inserted to bring another bandit to replace the originally defeated bandit. In the second example, a new radar site would be automatically inserted into the area in which the trainee strayed.

1.1 Lack of Knowledge Capture Methods and Tools

There exists a technology gap surrounding effective methods for capturing and maintaining critical training event data such as training goals, trainee decisions, trainee performance, etc. Scenario-based training provides an advanced framework for decision makers to be exposed to real tasks in a systematic way. It is also a practical approach because it facilitates the move toward an adaptive training paradigm, in which new incidents may be defined and deployed during the training exercise. Scenario-based training is composed of six main steps executed in a closed cycle: (i) Skill Inventory/Performance Data, (ii) Learning Objectives/Competencies, (iii) Scenario Events/Scripts, (iv) Performance Measures/Standards, (v) Performance Diagnosis, and (vi) Feedback and Debrief [1]. Under scenario-based training, trainers are responsible for monitoring trainees, providing feedback, diagnosing deficiencies and performing remediation. However, correct execution of all of these tasks represents a huge task overload on trainers that are involved in the scenario-based training process, and existing scenario definition tools lack comprehensive knowledge capture and knowledge management capabilities to compensate for this overload. Further, relations between the objects of the scenario and information about the relations that exist between objects in the scenario are not maintained, thereby making it nearly impossible to perform automated after-action review and historical analysis.

1.2 Lack of Knowledge Capture and Reuse Technology for Training

There exists a void in the availability of methods and tools for capturing and reusing training information from recurring training events. For example, tools are necessary to maintain information about the students participating in the training, their role types, their association to other training events, what roles they played in those events, their performance in those events, characteristics of their training regimen that they felt were most influential in their performance, etc. Further, mechanisms are needed to capture and use training lessons learned over recurring exercises.

1.3 Lack of Learning Mechanisms for Training Systems

Absent are adaptive automation mechanisms to improve the quality and content of training over time. Learning Management System (LMS) technologies must allow the students to provide scenario enhancements based upon their experience. In essence, the scenario definition system must "learn" about or adapt to new aspects of the training environment or objects in the system and allow the scenario developer to utilize these new facets in the generation of new scenarios.

1.4 Paper Outline

This paper describes simulation based methods and automation mechanisms that seek to address the above challenges. First, we will describe an ontology for adaptive simulation based training that provides a conceptual foundation for the adaptive training method. Next, we outline an adaptive simulation based training method. A mission-driven approach to measure performance is described. A summary of an automation architecture for adaptive simulation based training is then presented. Finally, the paper summarizes the benefits of our adaptive simulation based training method and outlines areas for further research. Illustrative examples drawn from the military training domain are used throughout the paper to describe key ideas.

2 An Ontology for Adaptive Simulation Based Training

The simulation based training method described in this paper seeks to address the training needs of defense missions. Mission requirements are the drivers for the training goals, which, in turn, drive the determination of warfighter training performance measures. An ontology (conceptual model) for adaptive simulation based training is shown in Figure 1. Knowledge, Skills, and Experiences (KSE's) must satisfy Mission Requirements as shown in Figure 1. 'Knowledge' is defined as "information or facts that can be accessed quickly under stress." Examples of knowledge areas include tactical plan coordination, team operating protocols, tactical maneuver principles, and team maneuver expectation templates [2]. 'Skill' is defined as "a compiled sequence of actions that can be carried out free of error under stress." Examples of skill areas include single mode selection to maximize information requirements, scan volume placement to maximize relevant information gathering, and radar control manipulation to locate and track relevant targets. An 'Experience' is defined by [3] as a "development event during training and/or career necessary to learn a knowledge or skill or practice a MEC under operational conditions." Dependencies between KSEs and Training Performance Measures provide an important requirement for determining the structure and content of the Performance Measures. Capturing these important dependencies is part of our strategy for designing mission-driven metrics as outlined later in this paper. In the context of simulation based training, Training Scenarios are decomposed into finer-grained building blocks called 'Drills.' A Drill is defined as the smallest building block of training simulation content. Drills may be grouped together into meaningful collections for building Training Scenarios (Figure 1). A key idea is the notion of adaptively composing/assembling simulation training material from building blocks of re-usable parts: drills and drill collections [4].

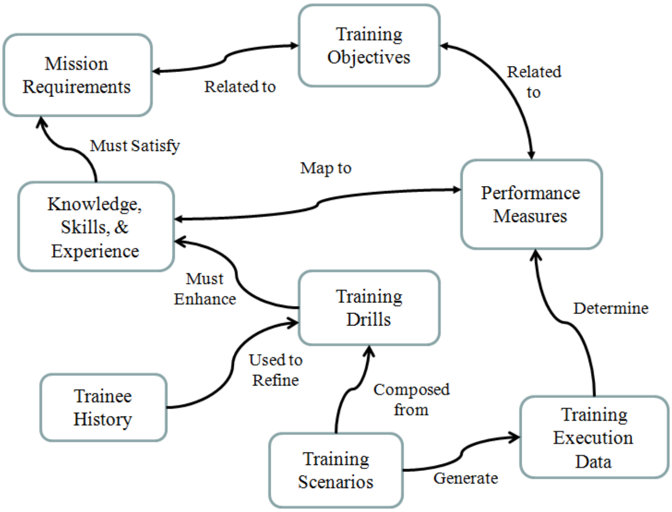

Fig. 1. Ontology Model for Adaptive Simulation Based Training

As indicated in Figure 1 the Training History of each student (often stored in 'Electronic Training Jackets') is used to individualize the training content (drills and scenarios) to address unique training gaps of different students. The execution of the scenario based training will generate simulation log data that is used to compute the values of carefully designed performance metrics as shown in Figure 1. The Performance Metrics must address Training Objectives and are mapped to the simulation drills. The Drills themselves are carefully engineered to induce the Skills and Experiences that address the warfighter mission requirements.

3 An Adaptive Simulation Based Training Method

This section describes a method for adaptive simulation based training. The method identifies the activities required for conducting simulation based training and the relationships between these activities in terms of the activity inputs, outputs, enabling mechanisms, and constraints. The IDEF0 function modeling method (www.idef.com) was used to represent the method, which is summarized pictorially in Figure 2.

The following paragraphs describe the adaptive simulation based training method in greater detail.

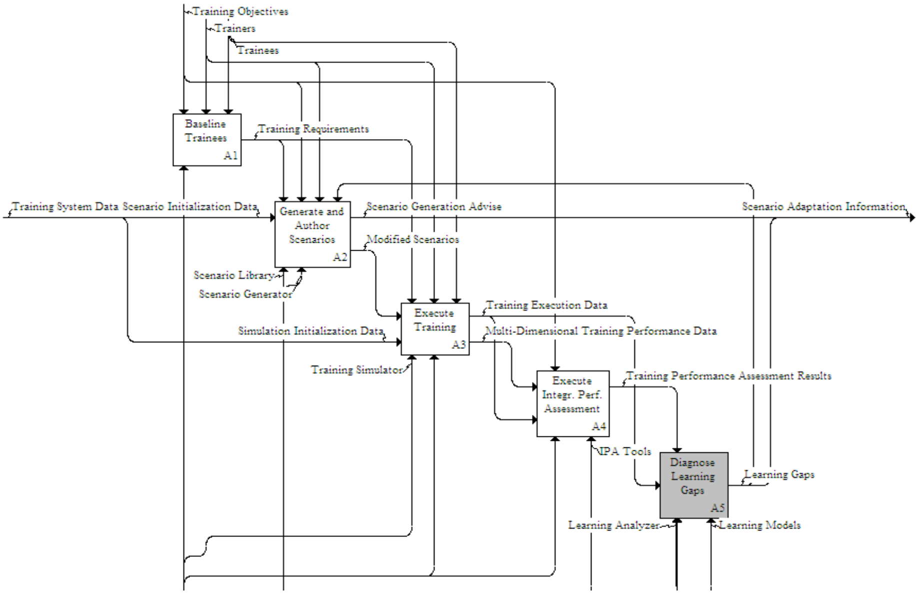

Fig. 2. Adaptive Simulation Based Training Method

Baseline Trainees: This activity involves performing benchmarking or testing performance at the point of entering the training sessions. For example, subjective evaluation methods may be used to baseline cognitive knowledge structures among trainees. The main outcome of this **activity** is a set of prioritized training requirements for the current set of trainees. These training requirements are used to inform subsequent activities in this methodology. For example, the training requirements are used to help determine the appropriate scenarios that best address the skill and experience needs of the trainees in the current training session. The baseline assessment results also provide a 'control data set' during the integrated training performance assessment activity.

Generate and Author Scenarios: This activity involves generating the following information: (i) identifying drills and collections of drills, and (ii) composing and sequencing drills to provide scenario design (and redesign) advice. A combination of rule-based methods and data analytics-driven methods may be used for scenario design information generation.

Execute Training: The scenario-based training simulation models are initialized with the mission-specific training data sets. The simulations are then executed. The training participants (trainees and instructors) interact with the simulation in a manner that induces the learning that is intended by the training objectives.

Perform Integrated Training Assessment: This activity involves using the results from the simulation based training event in order to measure the performance of the trainees (students). There are many different types and levels of performance metrics. The ability to scientifically measure performance is influenced by many factors including (a) the availability of a well conceived plan and the engineering design of simulation training instrumentation, (b) the availability of data generated during the training session, and (c) the availability of subject matter experts (e.g., trainers and research scientists). In general, performance metrics span many dimensions. The metrics may be *quantitative/objective* or they may be *qualitative/subjective*. In some situations, metrics are *binary*; these metrics are used to determine whether or not a particular event/action was enacted by the trainee (a 'Yes or No' type metric). *Time based* metrics measure time intervals (e.g., actual time of a particular response vs. the desired response time) and *proficiency metrics* that determine the level of the correctness of a response (e.g., how well was the threat discriminated vs. a decoy, how well did the trainee respond to large amounts of noise and distracters in the data, etc.). The design of metrics is influenced by the types of warfighter missions and the degree of sophistication of the simulation based technology and infrastructure that is available for training. The design of sound metrics requires significant and intentional effort. More research is needed in some areas of measurement and metrics; for example, the evaluation of cognitive states often requires the use of sophisticated sensing technology such as neuro-physiological sensors. Our mission driven performance measurement approach involves (i) determining training performance based on objective training performance data, (ii) determining training performance based on subjective training performance data, and (iii) fusing the results of the different performance assessments to determine an aggregated assessment of training performance.

Diagnose Learning Gaps: This activity will infer the training gaps by comparing actual performance with desired performance.

4 Mission Driven Performance Measurement Approach

The overall strategy/rationale for training performance metric design is: The measures must provide a means to evaluate whether the warfighter is learning to be more effective in supporting missions. This implies that the training results must provide warfighters with the Knowledge, Skills, and Experiences (KSEs) needed to address mission requirements. These requirements are often met in different ways: basic training, mission qualification training, continuation training, etc. Simulation Based Training (vs. Classroom/Schoolhouse Training) is often used for Continuation Training (for refreshing and updating KSEs and addressing critical gaps that occur because of constantly changing mission requirements).

We now provide more details of our approach. A simple urban combat training example is used to illustrate the main ideas.

Step 1: Identify Knowledge and Skill (KS) Categories: This activity determines the set of knowledge and skills that are being imparted. We have identified multiple sets of KS categories for different types of warfighter missions based on the extensive body of knowledge that documents combat knowledge and skill sets (for example, [5-7]). For example, [5] lists Knowledge and Skill categories for building a clearing mission in Urban Operations (UO): (i) diagnosing and predicting, (ii) situation awareness, (iii) perceptual skills, (iv) improvising, (v) metacognition, (vi) recognizing anomalies, and (vii) compensating for equipment limitations. Our research indicates that these KS categories are inherently linked to decision processes (i.e., rationale/reasoning for making decisions and taking action).

Step 2: Identify Mission Specific Task Sets: This activity determines mission specific task categories that are relevant to live combat training. These tasks manifest themselves at multiple levels of granularity and specificity. To illustrate, we use a simulation based UO warfighter training situation. In this situation, there are two broad categories of decision requirements: *task-focused* and *task-independent*. Task-focused decision requirements for building clearing missions are (i) determine how to secure the perimeter, (ii) determine how to approach the building, (iii) determine how to enter the building, (iv) determine how to clear the building, (v) determine how to maintain and extend security, and (vi) determine how to evacuate the building. Likewise, the task-independent decision requirements for building clearing missions are (i) maintain the enemy's perspective, (ii) lead subordinates, (iii) maintain the big picture and situation awareness, (iv) project into the future, and (v) understand and apply rules of engagement. The decision requirements are linked to specific parameters found in tactics manuals that provide instructors with guidelines for measuring performance against recognized standards of employment doctrine. Each of the decision requirements (task-focused and task-independent) are governed by critical decision and judgments. To illustrate, the "determine how to secure the perimeter" decision requirement is linked/tied to the following critical decisions and judgments: (i) determining how to seal off the area, (ii) determining where to place security assets, (iii) determining which assets and people to employ, (iv) determining where to concentrate fire, (v) determining how to synchronize fire and the shifting of fire, and (vi) if multiple buildings are to be cleared, determining which to clear first. A simulation based UO training engagement will provide training events/drills that induce critical decisions and judgments for these decision requirements.

Step 3: Design Metrics for Knowledge/Skills and Tasks Combinations: This activity formulates performance metrics for meaningful associations of Knowledge/Skills with (mission specific) Tasks. Figure 3 illustrates, by example, the idea of a metric that is determined through the association of knowledge/skills with tasks. Mission-specific tasks are listed for a building clearing mission in UO operations. All the tasks within a mission are governed by Tactics, Techniques, and Procedures (TTPs) or Pre-deployment Training Program (PTP) standards. TTPs are composed of parameters that instructors monitor against recognized standards of employment doctrine. Each task is decomposed into individual actions that the soldiers within a unit or that a specific soldier should perform to successfully complete the task. Instrumented training facilities and instructors record measurements on actions performed by soldiers. Objective measures may be determined from the simulation output log data, and subjective measures are recorded by training instructors [usually Subject Matter Experts (SMEs)] using pre-determined grade sheets. The preferred choice of assessing team performance is through subjective measures.

Every mission requires units to possess certain Knowledge and Skills (KS) to successfully execute and accomplish the goals. These KS are applicable across all the tasks, but it is possible that the degree of association (weights) might vary significantly. For example, "Improvising" might play a significant role for the "Approach the Building" task than for the "Secure Perimeter" task. We envision, for each pair of associations between KS areas and Tasks, that there exists metrics for quantifying team performance effectiveness. We have listed a few metrics and measures in the figure and how they relate to KS-Task association as follows:

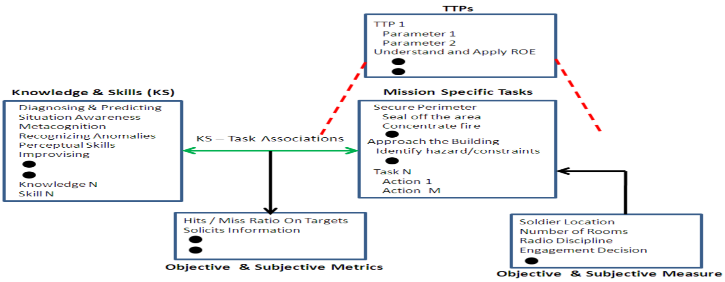

Fig. 3. Approach for Designing Metrics: An Example

- **Objective metric, "Hits to Miss Ratio On Targets":** this can be associated to the "Diagnosing and Predicting" and "Concentrate Fire" (*action within "Secure Perimeter" task*) pair.
- **Subjective metric, "Solicits Information":** this can be associated to the "Recognizing Anomalies" and "Identify Hazard/Constraints" (*action within "Approach the Building" task*) pair.

The above two metrics are given to illustrate the idea and approach for designing metrics.

Step 4: Determine Instrumentation Strategy: This activity refers to the creation of the means for deriving values of the performance evaluation metrics. This activity will be significantly influenced by the type of (post-) training data that is actually available within the simulation based training system.

5 Architecture of an Adaptive Simulation Based Training System

This section summarizes a conceptual architecture of a system that provides automation support for the 'Adaptive Simulation Based Training Method' described earlier in this paper (Figure 4). The functions supported by this architecture include (i) Integrated Training Performance Assessment, (ii) Learning Gap Diagnosis, and (iii) Adaptive Scenario Generation.

The architecture provides automated support for the adaptive generation of scenario based training simulations through (i) agile and comprehensive performance measurement and (ii) targeted training gap diagnosis. The Scenario Generation tool auto-generates scenario creation and scenario redesign information, allowing users to rapidly author/reconfigure scenarios to address the focused needs of the trainees. The scenario design advice is intelligently guided by the measured training gaps, the training objectives, and the desired performance goals. The Intelligent Performance

Assessment (IPA) Tools determine the values of training performance metrics by combining the results of three types of assessment: (i) neurophysiological-sensor based assessment, (ii) objective assessment, and (iii) subjective assessment. The IPA Tools use an 'information fusion' approach to integrate the measurements from the three different assessment methods. The Learning Analyzer compares the results of the IPA with the desired performance (based on the training objectives and the expertise level of the trainees). An important output of the Learning Analyzer is a prioritized set of trainee learning gaps that is addressable through redesign of the training scenarios. The architecture houses different types of knowledge models: (i) the Scenario Library, and (ii) the Knowledge Base (KB) that contains Rules, Fuzzy Rules, and Analytic Models.

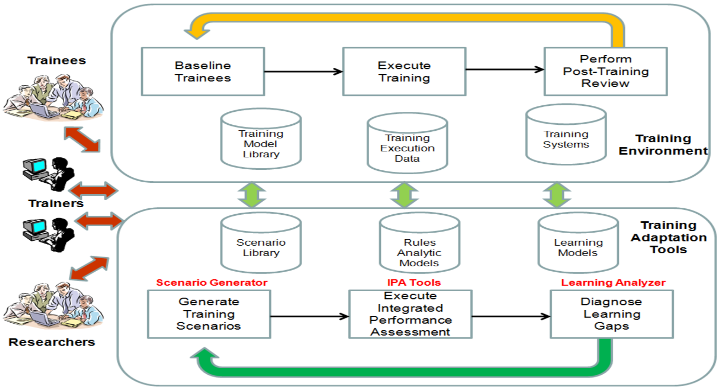

Fig. 4. Adaptive Simulation Based Training System Architecture

Finally, the Training Adaptation Tools subsystem interfaces with the 'Training Environment' that includes (i) Training Systems (this includes training simulators and the information infrastructure needed to manage the execution of simulation-based training), (ii) the Training Model Library (this refers to the collection of models used within the simulation-based training environment), and (iii) the Training Execution Data (this refers to the transactional data that is managed within the simulation-based training data; this includes simulation input data and simulation output data).

The adaptive simulation based training architecture has been implemented for air to air combat training with the U.S Air Force and the U.S. Navy. End user validation of this technology is currently ongoing within a laboratory setting [4].

6 Summary and Areas for Further Research

This paper described a structured method of adaptive simulation based training. Driven by an ontology model of adaptive simulation based training, the method characterizes the simulation based training activities and their interrelationships. A central element of the method is a mission-driven, information fusion-based approach for integrated performance measurement. Finally, an automation architecture is outlined that provides a pathway for realizing the practical benefits of the adaptive simulation based training methods described in this paper.

Key benefits of the research described in the paper include (i) significant reductions in time and cost to develop and maintain simulation based training systems, (ii) improved effectiveness and quality of simulation based training in response to dynamically changing and complex training needs and requirements, and (iii) a component-based architecture that enables rapid, affordable, and scalable technology insertion and deployment.

Areas that would benefit from further research include (i) design of mission-driven metrics and instrumentation methods to measure intuitive decision making capabilities during simulation based training, (ii) design of methods to rapidly tailor simulation based training to address dynamically evolving mission-driven needs of individuals and teams, and (iii) design of hybrid training methods and tools that combine (a) simulation based training, (b) game based training, and (c) computer based training.

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