HUMAN PATIENT MODELING

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ABSTRACT

This project has two goals. First, decrease the deaths due to combat wounds by having better trained medical staffs and, second, provide a mechanism for analysis and for test and evaluation (T&E) of issues in casualty medical treatment. To meet these goals, a prototype dual purpose training and analysis system is being developed that realistically and physically simulates the emergency medical treatment process from the time of injury through initial treatment at the field hospital. The central component of this system is a physical simulation of a casualty (an instrumented mannequin), the Human Patient Simulator (HPS). The HPS was developed for training anesthesiologists and provides a dynamic, physiologically accurate simulation of a patient whose condition must be diagnosed, treated, and monitored. The premise of this project is that improved training for combat casualty care will result from the treatment of "virtual casualties" simulated by HPSs from initial trauma throughout treatment and transportation.

This paper reports on the first phase of this project which provides a medical training and test and evaluation capability not achievable currently in force on force exercises. In this phase, the HPS was customized to simulate patients with combat trauma, linkage created to the Simulated Area Weapons Effects/Multiple Integrated Laser Engagement System (SAWE/MILES) force on force system, an ancillary medical simulation created, and a training or analysis methodology investigated. During SAWE/MILES force on force combat training exercises, virtual casualties occur when soldiers are "hit". A virtual casualty created by a SAWE/MILES Electronic Casualty card (ECC) is transferred to a HPS for initial treatment at a Battalion Aid Station through a new software prototype and then transported (if necessary) to a field hospital. From initial trauma to treatment at the hospital, medical personnel interact with ECCs and HPSs representing virtual casualties. The new software prototype models combat casualties and missing caregivers while the virtual casualties are not simulated by HPSs or ECC's.

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1. INTRODUCTION AND BACKGROUND

1.1. Problem Statement and Research Goals

The long term goals of this project are two fold. First, decrease the number of deaths due to wounds suffered in combat by having better trained medical staffs and, second, provide a mechanism for analysis and test and evaluation (T&E) of equipment, force composition and structure, and procedures in casualty medical treatment. Simulation provides the enabling technology to meet these goals. The Combat Trauma Patient Simulator (CTPS) research team is prototyping and evaluating a dual purpose training and analysis simulation system that realistically and physically simulates the emergency medical treatment process from the time of injury through initial treatment at the field hospital. The CTPS team is composed of the following team members; DoD Live Fire Test and Evaluation Office, US Army Simulation Training and Instrumentation Command, the University of Central Florida's Institute for Simulation and Training (IST), Lockheed Martin, Medical Education Technologies, Inc. (METI), and the Training and Simulation Technology Consortium.

The CTPS is based on existing technology and provides a dynamic, physiologically accurate simulation of a patient whose condition must be diagnosed and treated through medical and surgical intervention. An interesting facet of the research project is the unique blending of commercial and military hardware. A Human Patient Simulator (HPS) produced by Medical Education Technologies, Inc. is a commercial product used extensively to train a variety of health care practitioners. A Simulated Area Weapons Effect/Multiple Integrated Laser Engagement System SAWE/MILES based Electronic Casualty Card (ECC), developed by Lockheed Martin is the military component of the research effort. Both of these products are described later in this paper. IST provides the integrating mechanisms using DoD's High Level Architecture paradigm as well as a computer based version of the casualty and care giver.

The premise of this research project is that "virtual casualties" can be simulated by realistic physical simulations from the time of initial trauma throughout treatment and transportation. For example, during force on force combat training exercises using SAWE/MILES technology, casualties occur when soldiers are "hit" by laser beams representing direct fire (MILES) or probabilistically hit by indirect fire (SAWE). A virtual casualty is created by an Electronic Casualty Card (ECC), queued in a software simulation of the casualty, and transferred to a HPS for initial treatment by a medic. Each virtual casualty is treated by a medic at a Battalion Aid Station (BAS) and transported (if necessary) by helicopter or ground vehicle to a mini-Mobile Air Surgical Hospital (MASH). From initial trauma to treatment at the MASH, medical personnel interact with CTPSs representing the virtual casualties.

It is, however, impractical to have an HPS for each casualty. Fortunately, we believe only a few HPSs are needed because virtual casualties can be moved between HPSs. For example, a medic can treat multiple casualties at a Battalion Aid Station in sequence on a single HPS. Similarly, a helicopter can be equipped with one or two HPSs to train helicopter medical teams. Each virtual casualty "inhabits" a medic's HPS until transferred to a helicopter HPS. The helicopter medical team treats the virtual casualty(ies) during real or simulated transportation to a MASH. Similarly, training in casualty treatment can occur at the MASH using HPSs. When an HPS is not present, a software simulation of the casualty queues the 'patient'. Hence, individual casualties are represented throughout the time from initial trauma to arrival at the final care facility. This approach exercises the entire medical team and treatment process while allowing the real soldier to return to his unit as a replacement combatant to continue his combat training. This approach also creates a more realistic and complete battlefield environment than current field exercises.

Key features of this research effort are:

- the training and analysis takes place in the field with the operational equipment deployed with the unit,
- the casualties occur as a part of realistic combat exercises, and
- data can be gathered automatically throughout the casualty treatment process.

The first element is required to allow the medical teams to train in the field with the equipment they will be using in combat. The second element is required to present medical teams with the types of casualties at the rate seen in combat. The third element allows detailed after action review, evaluation, and analysis of the casualty care process.

1.2. Current Training and T&E Techniques

Currently, medic training in the military is conducted in a 10 week course. The training is limited from several perspectives. First, the level of training is not consistent with current civilian training and qualifications for Emergency Medical Technicians. This limitation restricts the number of medics because transition to civilian positions requires additional training and certification. Secondly, trainees can not encounter the frequency and diversity of casualties they may encounter in combat. Third, liability issues preclude training in many civilian hospitals. This latter issue restricts refresher training as the military reduces its number of hospitals. Other restrictions in training are also problematic. The situation is expected to worsen with time.

Test and Evaluation is also difficult because humans can not be used as subjects. The T&E community generally relies on analytic models, scripted events, and data from previous conflicts in their efforts to study the effects on casualties resulting from introducing new systems into the military inventory. New systems vary from major weapon systems to new medical equipment and procedures. It is difficult extrapolating or relating old data to new situations. Scripts represent one of a possible large number of situations.

As seen above, current techniques in training and T&E are not effective in reducing deaths due to wounds.

1.3. Current Systems Useful to Medical Simulation

The Medical Education Technologies, Inc./University of Florida Human Patient Simulator (HPS) is a full scale, fully interactive, life-like simulator that meets the needs of educators and learners in all health care professions (see Figure 1). Clinical features include palpable pulses, self-regulating control of breathing, heart and breath sounds, electrocardiograms, pulmonary artery pressure, and thermodilution cardiac outputs, among others. Physiological and pharmacological models direct simulated patient responses (both normal and pathophysiological) to drugs, mechanical ventilation, and other medical therapies.

The HPS is a model-driven system. Virtually all simulator responses are automatically and dynamically determined by sophisticated physiological and pharmacological models. Patient physiology is defined by patient profiles and can be modified either "on-line" or through scripts. Numerous pre-configured profiles and scenarios are provided, encompassing a variety of pathophysiological conditions. Using patient and scenario editors, custom profiles and scenarios can be created.

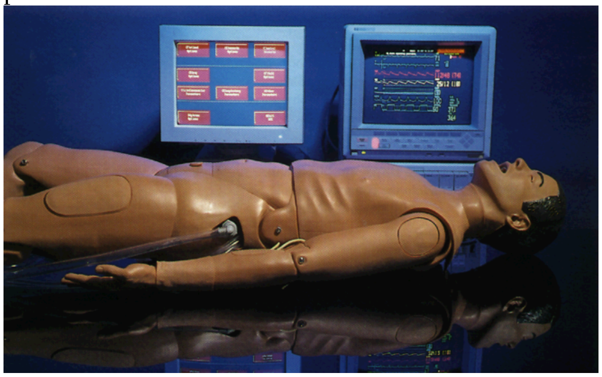

Figure 1. Human Patient Simulator

The Electronic Casualty Card (ECC) is part of the SAWE/MILES equipment manufactured by Lockheed Martin Electro-Optical Systems, Pomona, CA (see Figure 2). The system is called MILES II. The ECC is a PROM which is added to the MILES equipment. The ECC augments use of MILES by providing in excess of 40,000 symptom/treatment conditions. Injury areas include the head, neck, torso, abdomen, arms, legs, and hands.

When a soldier is injured in MILES, a casualty is generated by the ECC. The casualty starts a timer during which the soldiers "condition" degrades. Medical intervention is achieved by a medic using an interrogator. The interrogator reads the injury and provides the medic with a description and a list of possible treatment strategies. The medic selects one treatment and transmits the information back to the ECC. Patient condition adjusts accordingly within the limitations of the ECC. Close proximity between the medic and casualty must be maintained.

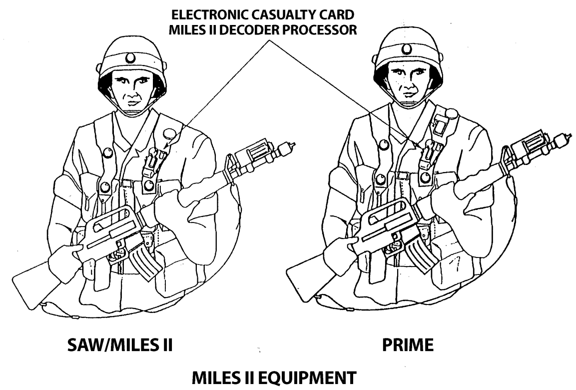

Figure 2. MILES II with ECC

Other developing simulation technologies will be used on the CTPS. Included in this list are the ModSAF and High Level Architecture. ModSAF provides an existing vehicle level automated forces platform. The High Level Architecture provides a connectivity paradigm being promulgated by the DoD as well as a mechanism for capturing simulation capabilities and interactions. These latter mechanisms are particularly useful to the CTPS in connecting disparate systems and in developing new simulation capabilities.

2. CURRENT DESIGN

This paper describes, a Phase One architecture that interconnects four different simulations using the DoD's High Level Architecture (HLA). The four components are the HPS, the ECC (i.e., MILES II), ModSAF, and a new software simulation being prototyped by IST. The new IST software, called PatSIM, models the physiology of the patient and functionally interfaces the ECC to the HPS. The HLA provides a flexible infrastructure for connecting disparate simulations to form a larger distributed simulation. In HLA terms, the CTPS system is an HLA federation and is, we believe, the first medical federation to be developed. This architecture allows additional nodes to be added to the CTPS federation with minimal cost and difficulty in later phases of the project.

Pictorially, the architecture is shown in Figure 3.

The HLA Run Time Infrastructure (RTI) provides the communication backbone of the Combat Trauma Patient Simulation. RTI routines provide the services for starting/stopping a federation simulation run (called a federation execution), for allowing simulations to join and leave the execution, and for simulated objects to interact.

The chief advantage to using the HLA RTI is to reduce the cost and risk of developing and maintaining the inter-simulation communication system. Because the underlying communication system is provided by the RTI, only the application interface to the RTI needs to be developed, a much smaller effort. Based on experimental results with the prototype RTI from other programs, the DoD is developing new, higher efficiency RTIs. Because the RTI Application Programmer's Interface (API) remains constant across versions of the RTI, there should be little or no cost to upgrading RTIs.

The availability of the IST HLA-DIS/SIMNET Gateway (hereafter, just "Gateway") provides an additional cost savings. The Gateway was originally developed as a bridge between DIS and the RTI and was used in the Platform Proto-federation to connect a SIMNET M1 simulator to the federation. The Gateway will be used in two forms by this project. First, the Gateway will be used unaltered as a bridge between ModSAF and the CTPS RTI to bring ModSAF vehicles into the federation. Second, the Gateway will be modified to provide RTI interfaces to the ECC, the HPS, and the PatSIM.

Creating an HLA federation requires that a Simulation Object Model (SOM) for each simulation within the federation and a Federation Object Model (FOM) for the entire federation be defined. Each Object Model consists of a series of spreadsheets that define the object class hierarchies, the attributes of each object, and the interactions among objects.

The HPS is a stand alone physical simulation of a human patient that uses a PC based application for software simulation. The HPS Internal Data Exchange Protocol (HIDEP) allows commands to be given to the HPS software over a serial line. This project will connect the HPS to the RTI via an application (called the HPS RTI Interface) that translates information between the HIDEP and RTI service calls.

The HPS RTI Interface will be a modified version of the Gateway. The modifications consist principally of removing the RTI to DIS/SIMNET translation process and then building an application using the Gateway's RTI API to accept "ownership" of a casualty and to communicate changing HPS physiological data to the

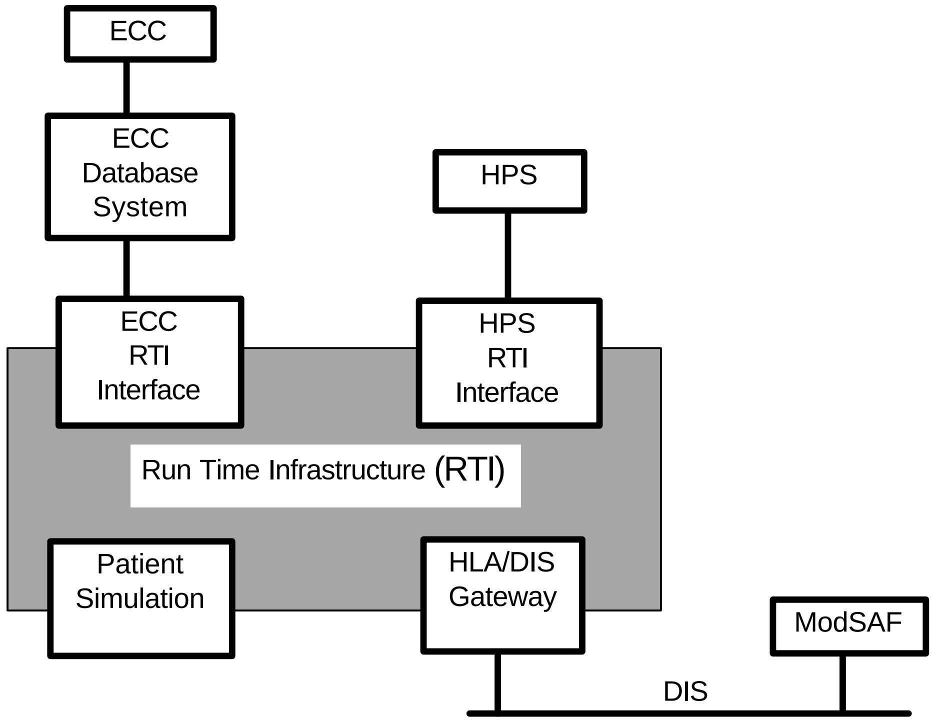

Figure 3. Combat Trauma Patient Simulator Architecture

federation. The HIDEP will be used by the HPS RTI Interface to communicate with the HPS.

The patient simulation (PatSIM) simulates the casualties while they are not being simulated by other federates (specifically, the HPS for this first phase). Four existing simulations were evaluated for use as the PatSIM: ModSAF, MedSAF, a software HPS, and ORCA. None appeared suitable for use.

Instead, a normative model based on the HPS will be developed in Phase One as the initial PatSIM. The approach for developing a normative patient model is described below. In Phase Two, the HPS simulation will be converted to a companion software only simulation to provide a high fidelity, dynamic physiological casualty simulation. Also, it is our intent to have PatSIM accommodate a variety of other patient models (e.g., the ECC) and mitigate differences between simulations.

Developing a normative model based on the HPS has several advantages over the other candidates. First, the cost of development is reduced for two reasons:

1. the PaSIM will be built on top of the modified Gateway developed for the ECC and HPS RTI Interfaces thereby reducing the cost to develop the communication system and
2. the normative model is more easily implemented than modifying an existing simulation. Modifying ModSAF to be a medical simulation appears to be difficult. ORCA appears to require significant modification to model ongoing physiological processes. Additionally, ORCA is oriented to assessing combat effectiveness while the CTPS is oriented to treatment. Later phases of the project may reconsider using ORCA as a tool for adjusting the combat effectiveness of an ECC equipped MILES II.

Second, the physiological values output by the HPS and PatSIM align better. Third, verification and validation (V&V) of the HPS supports V&V of PatSIM. Fourth, the Phase One normative model positions the project for a HPS physiological model in Phase Two. Fifth, each simulation is used in areas for which they were designed. For example, ModSAF is a vehicle simulation and will be used for simulating vehicles. PatSIM will simulate physiological processes without being encumbered with non-medical issues.

The normative model will be based on HPS data output. Each of the demonstration trauma types will be simulated on an HPS without medical intervention and the physiological parameters recorded. The lack of medical intervention is similar to a casualty not receiving medical care on the battlefield. The data log will be the source information for PatSIM casualties. PatSIM will, in essence, play back the HPS output for each casualty. Future phases of the project will support dynamic effects of physiology in PatSIM which are similar to the HPS. Medical intervention through a SAF model of a medical practitioner will also be introduced in future versions of the CTPS.

The ECC is designed to store information for download after an exercise. To allow real time insertion of MILES/SAWE casualties into the CTPS federation, a PC application based on the ECC database system will be developed to create casualties in the CTPS federation as they occur. In a production system, this ECC Database System would likely be a centralized data collection and distribution system connected to ECCs in the field via radio links for real time data acquisition. A production version, therefore, will route after exercise data differently than CTPS data.

The ECC Database System will be connected to the RTI via an application (called the ECC RTI interface) that translates information between RTI service calls and a special purpose protocol understood by the ECC Database system.

The normative model will also align with ECC outputs providing a smooth interface between casualty generation, time lapses in treatment, and subsequent treatment in the HPS. The ECC provides a rich set of casualty types (in excess of 100) consistent with standard military doctrine. The ECC's time based simulation is interfaced with the time and event based simulation using PatSIM. The initial design is to instantiate a credible data flow between ECC, PatSIM, and the HPS. Accordingly, a limited set of medical scenarios are being implemented. Specifically, a gunshot wound, allergic reaction shock, and mine encounter will be the three scenarios originating from the ECC. The PatSIM will handle these injuries, but not treat them. Handling will include allowing time to elapse as well as formatting data for transmission to the HPS whenever requested. The HPS can request transfer at any point in the scenario.

ModSAF will provide the simulated helicopters and ambulances for transporting casualties on the battlefield. No changes to ModSAF are necessary, however an enhancement to ModSAF will be made if time and resources permit to record the number of casualties being transported.

ModSAF will be connected to the CTPS federation via the Gateway. Some minor additions to the Gateway to support the evacuation vehicles will be necessary.

Because the CTPS is founded on the HLA, understanding the HLA concept of "attribute ownership" is necessary for understanding the flow of information within the CTPS federation. In the HLA, the objects things being simulated have attributes. The values for an object's attribute come only from the simulation that owns that attribute of that object. Hence, HLA allows an object to be simulated "in parts" by separate simulations; i.e. each simulation doing some of the object's attributes. Further, HLA allows ownership of attributes to be transferred between simulations. CTPS makes use of attribute ownership and attribute ownership transfer to build a simulation of a casualty from individual casualty simulations comprising the federation.

Table 1 summarizes the attributes and attribute ownership ("y" means simulation owns attribute permanently, "t" means attribute ownership is transferred to and from this simulation):

In summary, a casualty has five static attributes (they don't change over time): WoundType, WeaponType, BodyArea, WoundSeverity, and RecommendedAction; one dynamic non-physiological attribute: Location; and six dynamic physiological attributes: BloodPressure (BP), ResprationRate (RR), HeartRate (HR), CO2ArtierialPartialPressure (CO2APP), O2ArtierialPartialPressure (O2APP), and ArterialO2Saturation (O2Sat).

At points throughout the federation execution, casualties will be transferred to the HPS. Operator input at the PatSIM will initiate each process.

To transfer the casualty to the HPS, the PatSIM will request (via RTI service calls) that ownership of the six physiological attributes be transferred to the HPS. On behalf of the HPS, the HPS RTI Interface will accept ownership of the attributes. Then, using the internal representation of the casualty, reflected attribute values, and HIDEP commands, the HPS RTI Interface will cause the HPS to begin simulating the casualty. While simulating the casualty, the HPS will inform the HPS RTI Interface of changes in the physiological attributes via HIDEP messages. Finally, the HPS RTI Interface will update the changed attributes for consumption by the CTPS federation.

attribute	**ECC RTI Interface**	**HPS RTI Interface**	**Patient SAF**	**ModSAF**
Location	y			
WoundType	y			
WeaponType	y			
BodyArea	y			
WoundSeverity	y			
BloodPressure	t	t	t	
RespirationRate	t	t	t	
HeartRate	t	t	t	
CO2ArterialPartialPressure		t	t	
O2ArterialPartialPressure		t	t	
ArterialO2Saturation		t	t	
RecommendedAction	y			

Table 1. CTPS Attributes and Their Ownership

Virtual casualties are created at the ECC in response to a MILES/SAWE "hit". The ECC Database System will detect the virtual casualty and send casualty information to the ECC RTI Interface. The ECC RTI Interface creates the casualty in the CTPS federation. The casualty is created by the ECC federate issuing an RTI "Request ID" service call. The Request ID service call then informs the federation of the initial attribute values through an RTI "Update Value" service call. The ECC RTI Interface owns and updates all the casualty attributes except CO2APP, O2APP, and O2Sat. Since the ECC does not model changing the physiological attributes over time, only one attribute update for each attribute will be issued by the ECC RTI Interface.

The RTI informs the HPS RTI Interface and the PatSIM that a new casualty has entered the simulation through the "Discover Object" service. The HPS RTI Interface creates an internal representation of the new casualty and accepts attribute values that the RTI reflects. The PatSIM also creates an internal representation for the casualty and requests ownership of the BP, RR, and HR attributes be transferred to it. Simultaneously, the PatSAF begins updating the CO2APP, O2APP, and O2Sat.

To simulate the evacuation of a casualty via a ModSAF vehicle requires only that the casualty's location attribute mirror that of the evacuating vehicle. "Board" and "deboard" interactions will be defined within the FOM to coordinate casualties boarding and deboarding evacuation vehicles. The ECC RTI Interface and PatSIM will subscribe to the location attribute of ModSAF evacuation vehicles so that they know the vehicles' locations. The PatSIM operator will initiate an evacuation by selecting a casualty and a vehicle. PatSIM will issue a Send Interaction with a Board interaction specifying the casualty and the vehicle. The ECC RTI Interface will monitor the vehicle's location and update the casualty's location to mirror the vehicle. To deboard the casualty, PatiSIM will issue a Send Interaction with a Deboard interaction specifying the casualty and vehicle which will cause the ECC RTI Interface to stop mirroring the vehicle's location.

Another approach to simulating evacuation involves transferring the Location attribute to PatSIM so that it (rather than the ECC RTI Interface) would mirror the vehicle's location without involving the ECC RTI Interface. We choose the first approach to demonstrate the capability to manipulate a casualty's attributes across multiple federates.

3. FUTURE EFFORTS

As indicated above, this is the first phase of a multi-phased research effort. Future activities will involve the following;

- evaluations by groups in the training and T&E communities
- increase in the number of casualties accommodated by the CTPS
- bi-directional transfer of control and data between the ECC, PatSIM, and the HPS
- ability to have patients queue in the ECC
- ability to interoperate with other simulations
- ability to treat PatSIM patients
- a more robust PatSIM which has dynamic effects
- ability to treat head trauma in the HPS

4. CONCLUSIONS

A robust simulation capability is being researched and prototyped in the CTPS project. Research efforts, emerging technologies, and existing products are being merged to create a system with new capabilities described below. In addition, the unique arrangement of government, industry (commercial and DoD), and academia is a model of a new paradigm for developing and producing new products.

To achieve the goal of reducing deaths due to combat wounds, use of the CTPS in training will allow DoD organizations to:

- provide better training of its allied health care medical personnel than the current 10 week training program,
- establish more efficient sustainment training for military medical practitioners than current techniques,
- use training time for combat personnel more effectively, and
- provide military physicians with better training in caring for battlefield casualties.

To achieve the goal of providing a mechanism for analysis and T&E of medical related issues, analysis of exercises and experiments involving the CTPS will allow DoD T&E components to:

- thoroughly test and evaluate equipment (actual or proposed) in realistic battlefield scenarios,
- thoroughly exercise, evaluate, and refine existing and new casualty care techniques and procedures in realistic battlefield exercises, and
- analyze CSS and logistics issues in treating combat casualties.

This research program is intended to mitigate existing limitations in training for combat casualty care. New or improved capabilities will include:

- Practical experience in operational settings. The integrated CTPS lets medical personnel see more casualties than currently possible. The conditions under which those patients are seen can be varied.
- No medical liability issues associated with human patients in training, T&E, or analysis.
- Unbiased assessment and after action review of training, T&E, or analysis.
- Relieve issues associated with sustainment training of military personnel at civilian hospitals and health centers. As the military downsizes, sustainment training opportunities at military installations are being reduced. Outsourcing this training to civilian hospitals raises issues with respect to throughput of students, liability, and informed consent.
- Allow training of medical personnel in a more rigorous setting than currently required by the military.

Authors

Brian Goldiez is the Deputy Director at the Institute for Simulation and Training and Principal Investigator for the CTPS Program. He has over 20 years experience in Modeling and Simulation with DoD, Industry, and Academia. His current research interests include Graphics Systems, integration techniques, and vehicle modeling. Mr. Goldiez has a Bachelor of Science in Aerospace Engineering and an MS in Computer Engineering.

M. Beth H. Pettitt has been a civilian Department of Army Engineer for nine years. She has been involved with Modeling and Simulation since 1993. Recent programs at STRICOM have included the Omni Directional Treadmill and DIS Standards. She has a Bachelor of Science in Mechanical Engineering and is working towards a Masters in Engineering