Non-Lethal Effects and Crowd Behavior M&S Test Bed

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ABSTRACT

In today's urban conflicts, there is a real need to use emerging non-lethal weapons technology to reduce fratricide in an environment where friendly, neutral and hostile forces are all in close proximity. A simulation test bed to model crowd responses to non-lethal kinetic and directed energy weapons is required. This M&S capability provides for rapid experimentation and analysis of non-lethal effects on crowds with a focus on development of realistic directed energy models, improved crowd behavior models, and effective analysis tools.

In this paper, we discuss the components/interoperability of the test bed, lessons learned and challenges. Specific attention is given to the crowd model developed, non-lethal weapons, and analysis tools. One Semi-Automated Force (OneSAF) was chosen as the Semi-Automated Forces engine to drive force employment. Since OneSAF does not model non-lethal weapons, we created a series of non-lethal kinetic and directed energy weapons. The Joint Crowd Federate™ (JCF) is used to support the critical crowd modeling function. This paper discusses the enhancements to which improved the sophistication and relevance of the model by taking into account emotional states of the individuals in the crowd.

Newly developed custom Protocol Data Units (PDUs) in the federation provided a rich mix of crowd behavior data for collection and analysis. Since this emotional data cannot be analyzed by traditional simulation visualization, we developed an effective visualization tool that overlays an individual's emotional state with the individual's movements within the crowd. Additionally, a full array of metrics reports and graphs were developed to analyze both the weapons and crowd behavior aspects of the test bed.

ABOUT THE AUTHORS

Tina Gaumond is a Systems Engineer for Network Centric Systems, Raytheon. She was the Technical Lead for the Non-Lethal Effects and Crowd Behavior M&S Test Bed. Ms Gaumond earned her B.S. in Mathematics and B.A. in Psychology from the University of Nevada, Las Vegas. She then continued her education at Texas Tech University and earned a M.S. in Mathematics. Currently, Ms Gaumond is a PhD Candidate and is completing her dissertation in Applied Mathematics at Texas Tech University in the area of Ocular Dynamics.

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Lisa Jean Bair (formerly Moya) is Chief Scientist of WernerAnderson and leads its M&S research and development effort. She is co-chair of the M&S Congressional Caucus Standing Committee in support of M&S Professional Development and Education. She is also on the National Training and Simulation Association (NTSA) sponsored Certified Modeling and Simulation Professional (CMSP) Board of Directors. Ms Bair is a PhD candidate in the Modeling and Simulation program at Old Dominion University. Her research interests include agent based simulation, human behavioral modeling, simulation theory and formalisms, and validation.

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BACKGROUND

In today's urban conflicts, there is a real need to use emerging non-lethal weapons technology to reduce fratricide in an environment where friendly, neutral and hostile forces are all in close proximity. A simulation test bed to model crowd responses to non-lethal kinetic and directed energy weapons is required. This M&S capability provides for rapid experimentation and analysis of non-lethal effects on crowds with a focus on development of realistic directed energy models, improved crowd behavior models, and effective analysis tools. In this paper, we focus on the crowd model, non-lethal weapons model, and analysis tools developed as part of the non-lethal weapons test bed developed in partnership by Raytheon, WernerAnderson, and Virginia Modeling, Analysis, and Simulation Center.

One Semi-Automated Force (OneSAF) was chosen as the Semi-Automated Forces (SAF) engine to drive force employment. Since OneSAF does not model non-lethal weapons, we created a series of non-lethal kinetic and directed energy weapons. The Joint Crowd Federate™ (JCF) is used to support the critical crowd modeling function. This paper discusses the enhancements to which improved the sophistication and relevance of the model by taking into account emotional states of the individuals in the crowd.

Non-Lethal Weapons and Gaps in SAFs

Traditionally, SAFs have strictly dealt with lethal weapons. Unfortunately, this also has lead to the traditional shoot to kill algorithms embedded in these SAFs. This lead to several challenges: 1) the need to alter the SAF to incorporate non-lethal weapons modeling 2) the need for the non-lethal weapons models to not actually kill entities as they traditionally do in SAFs, 3) the need to find a crowd model capable of federating in a test bed with realistic crowd behavior to non-lethal effects and 4) a capability to analyze non-lethal effects for Concept of Operations (CONOPS), Techniques, Tactics and Procedures (TTPs), evaluation of modeling and simulation tools for later test bed inclusion, and training.

Need for a Crowd Model

Armed forces are increasingly required to operate among large number of non-combatant civilians. When dealing with a crowd, soldiers must operate much more like a police force rather than a military force that is dealing with enemy combatants. Non-lethal weapons (NLWs) provide a critical tool to armed forces that must deal with civilians in scenarios of unrest. Measuring the effectiveness of using NLWs in critical situations requires modeling and simulation tools that go beyond the traditional models of tactics and kinetic effects. Unlike kinetic weapons, the goal of a NLW is to control an individual or a crowd without inflicting permanent damage. In cases of large crowds, it is also reasonable to assume that NLWs can only affect a small portion of the crowd in a direct fashion. Crowd control through the use of NLWs requires changing the psychology of the crowd, effectively creating a force multiplier that addresses the root cause of crowd behavior. Making the situation more complicated is the fact that non-combatant pedestrians may be hostile towards the military forces and exhibit threatening behaviors. An incorrect reaction when dealing with such behaviors can often have unexpected consequences.

To the degree that the outcome of such situations depends on the emotional evolution of the crowd members, any approach that attempts to model crowd behavior must incorporate the cognitive and psychological aspects of crowd dynamics, in addition to the mechanical aspects of crowd motion. Existing literature provides an extensive foundation on which to base crowd behavior dynamics. More than a century ago, crowds were described as a mass of non-rational, like-minded individuals who lose their individuality and are swept up by crowd mentality (LeBon, 1896). More recently, Rohlinger and Snow (2003) have described four theoretical perspectives that have been used to better understand crowds and social movements. One of the most interesting perspectives offered in that research is that people are rational decision makers and will be most likely to participate in collective action when participation is rewarding or less costly than inaction.

Another area of research that is relevant to crowd dynamics and NLWs is that of spreading attitude effect. Research has shown that evaluation of disliked exemplars may spread to unrelated targets (Walther, 2002), or simply stated, spotting one or two angry faces in a crowd often leads to the belief that the emotion of anger is shared by the rest of the crowd. Basic research on face perception has shown that perceivers orient toward threatening stimuli, and angry faces are more visible within a crowd (Hansen & Hansen, 1988). Also, it has been shown that negative faces capture attention and crowd members focus on such faces (Eastwood, Smilek & Merikle, 2001).

The extent to which emotions actually spread among crowd members is referred to as entitativity (Campbell, 1958) or the extent to which crowd members feel like they ‘belong’ together. Reportedly, the degree of entitativity experienced by crowd members ultimately determines the set of actions demonstrated by a crowd (such as organizing a strike or a demonstration, engaging in mass violence, helping each other, etc) when faced with situations of different emotional valence ranging from fear to anger to joy. Finally, another relevant concept is perception of fairness. Research has shown (Drury 2003) that it is not necessarily the use of force that creates unrest, rather the perception of unfair use of force. In fact, depending on the crowd composition, fair and selective use of force (i.e., control of a select few individuals that are causing trouble) can have a positive effect on crowd psychology, whereas indiscriminate or disproportionate use of force can aggravate a crowd, increasing entitativity.

In summary, the extent to which emotion is shared by members of a crowd has consequences for approach/avoidance response tendencies. Typically, crowd members form an expectancy about the emotional state of the crowd which drives them to a particular behavior. While there is ample evidence for physical factors such as noise, physical force and injury impacting crowd behavior, the primary variable that translates physical forces into action components is emotion. Therefore, it is vital that the generation of models of crowd behavior be based on a representation of both cognitive (affective/emotional) states as well as physical states.

Purpose of Project

This test bed was developed to provide a standing modeling and simulation capability for rapid experimentation and analysis of non-lethal effects on personnel with a focus on development of 1) realistic directed energy (DE) and non-lethal kinetic weapon models, 2) improved crowd behavior models, and 3) effective analysis tools.

TECHNICAL CHALLENGES

Weapons Models

Two non-lethal kinetic weapons, the M203 40mm Grenade Launcher and the M500A1 12 ga Shotgun, were modeled within Joint Conflict and Tactical Simulation (JCATS) and OneSAF. Furthermore, two directed energy weapons were modeled (unmounted and mounted on vehicles): Active Denial System 2 and Silent Guardian.

Several munitions for the non-lethal kinetic weapons were modeled using data from AMSAA Technical Report TR-2006-23 (Fitzgibbons, Peters, 2006). In OneSAF, the M1012 Rubber Fin Stabilizer Shotgun Round and the M1006 40mm Sponge Round were modeled. However, these munitions used the same accuracy data for the lethal weapons. So the vulnerability effects were changed to have no chance for undesirable effects. The weapons, therefore, will detonate on targets but never hurt them. In JCATS, we modeled the same munitions in OneSAF and several others: M1029 Stingballs Area Round, M1013 Stingball Area Round, Beanbag Round, Slug round, 00 Buckshot Round, and the Flachette Round.

Within JCATS, current implementation of a beam model accounts for a planned direct fire at an entity or an area for suppressive fires. For a suppressive fire, the user defines an area on the 2D display for the target. Then the beam is swept across the area. For a planned direct fire event at an entity, the distance from the weapon to the target determines the diameter’s beam and the center of the beam is half of the targets height. The beam itself is then modeled with seven beamlets that represent the diameter of the beam. Specifically, the width of the beam is defined by three of the seven beamlets (JCATS Vista Editor User Guide Ver. 7.1.0, 2007).

The model in JCATS has limitations. For example, if range to a target is large, the beam may miss the target because the diameter of the beam may be too wide. There are gaps between the beamlets that are not accounted for. The larger the diameter of the beam creates the gaps to be larger between the beamlets. Also, since the beamlets were fixed, this created an issue where one or two beamlets would detonate on an entity and the remaining would display in the metrics as failure to make contact with an entity.

Modeling the directed energy weapons (DEWs) in OneSAF proved to be a challenge since there are no beam models and required modifications to the OneSAF 2.1 core baseline. DEWs models were assumed to be projectiles with target visibility algorithms that assume a simple "zero-width" line-of-sight path. As a result widths of entities were not taken into consideration, only height was considered.

Raytheon's OneSAF Directed Energy Model represented the effect of the beam's volume by calculating targets potentially intersecting the beam and then firing beamlets on each potential target. This enabled the model to only show detonations on entities actually targeted and actual failures that did not make contact with entities.

Psychologically based crowd model

The basic model used for creating the crowd used in this project is based on a typical agent-based paradigm. Each crowd member possesses self awareness that is instantiated by a vector of variables that fully account for the character's state at any point in time. The state vector contains both the cognitive as well as physical state of each character. The state of each character dictates the actions exhibited by that character. These actions in turn affect the environment either because they change the perception of the character or because of their effect on other characters. The agent-based model loop is closed when each character perceives stimuli which in turn affect the future values of the state. The overall model is parameterized through the use of multiple parameter tables that contain various coefficients and other calibration constants. A high level block diagram of the agent model is shown in Figure 1.

The components of the cognitive state have been selected to include primary emotions that in their totality represent a wide variety of emotional and cognitive states relevant to inter-crowd relations. In effect, these components form an emotional basis, much like a vector basis which contains linearly independent vectors that can describe a vector space. When referring to emotions, proving linear independence is not possible, however, psychological research provides evidence on the existence of a set of primary emotions with which we can describe all other

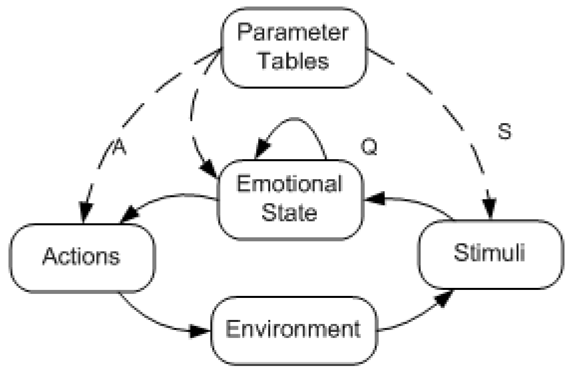

Figure 1. Block level diagram

emotions. These emotions include fear, anger, and joy. The model also includes surprise and pain.

Fear, by definition is an unpleasant emotion that reflects awareness or anticipation of danger. It can range from concern to outright panic. Anger is an emotion that shows up when we react to threats and is linked to self-preservation. Joy refers to emotional energy and fullness of emotions, but does not necessarily imply happiness. Surprise is an inherently transient emotion that occurs in response to unexpected events. Pain is defined as an unpleasant sensory and emotional experience associated with actual or potential tissue damage. Even though a stimulus, it is represented as a state in the model in order to capture the dominant effect that significant pain has on one's actions.

States

During this project, the JCF was improved from version 0.4 to version 1.0. Version 0.4 was the first version of JCF to include this more robust emotional state vector (fear, anger, and joy), the pulse state of surprise, and the physical state of pain. However, version 0.4 utilized a simplistic process for mapping cognitive states to actions which was derived from the original research prototype described in Moya, McKenzie, and Nguyen's work. JCF version 1.0, developed during this project, was completely re-architected for a more streamlined state calculation; more stable and robust computation; better external interfaces; new scripting capabilities; and expanded reactions to enable NLW responses.

Another improvement compared to previous versions of JCF, which used a discrete cognitive state vector, was the implementation of a continuous state vector with a significantly improved feedback loop between the stimuli and cognitive state. A decay term was added to the cognitive states to simulate the dissipation of emotions over time. Further, moving from the limited generic crowd member descriptors found in versions 0.3 and 0.4, version 1.0 now makes it possible to instance any number of characters each with their own set of behavioral parameters. This was required to support the need to have specific and identifiable aggressors within the crowd.

Version 1.0 was improved so that the future values of the state are affected by the current state as well as stimuli received in the recent past. For this project, a simplified linear stimuli effect model was used. According to this model, presence of a stimulus has a linearly increasing or decreasing effect on each state, according to a specific coefficient. Equation 1 provides the formulation, where q_t represents the state at time t, and s_t is the stimulus at time t. The coefficient k^{ij} controls the direction and rate of the effect of stimuli j on state i.

$$q_{t+1}^{i} = q_t^{i} + k^{ij} \cdot s_t^{j} \quad (1)$$

Stimuli

A key decision that has to be made in setting up a simulation is which stimuli will be included in the model. For this particular experiment, the focus was based on emotional reflection, a concept according to which we tend to feel the same way as the people we observe. This concept presumes a culturally similar crowd with members that are likely to be associated and sympathetic with each other. A set of stimuli reflecting perception of the three central psychological states were used, specifically *SeeAnger*, *SeeFear*, *SeeJoy*, *HearAnger*, *HearFear*, *HearJoy*. In addition, a stimulus was used to capture the dissatisfaction when aid was exhausted. The stimulus coefficients were set to increase anger. Note that the last stimulus was directly injected into selected characters, acting as the seed for the possible crowd disruption.

Version 0.4 demonstrated the feasibility of providing stimuli from NLWs. Version 1.0 expanded on this proof of feasibility by adding NLW stimuli for kinetic rounds such as rubber bullets intended for non-fatal blunt trauma on the human target, and low-power directed RF millimeter wave energy intended to create a burning sensation in the skin on the human target. While version 0.4 modeled these effects through a short-duration surprise event, version 1.0 added more robust capability by providing the ability to force a state in response to stimuli or to external scripting.

This capability is very useful because it supports the external instigation of specific emotions as well as physical conditions into the crowd model without requiring the crowd model to employ a high fidelity simulation of the delivery of such stimuli. As an example, consider the use of an Active Denial System (ADS). It is well known that once activated, the weapon will cause short-term pain, provided that it is aimed appropriately and is within a certain distance of the target. Firing this weapon can easily be integrated into the crowd model through this mechanism. The crowd model does not need to be aware of the cause and sequence of events that caused the pain, and it does not have to simulate the physics of delivery, hit ratio or other factors, which are left as the responsibility of an external program that can perform the domain-specific simulation for a particular weapon. Once the external simulation has determined successful weapon discharge, the known effect can be forced upon the crowd member as required.

The overall organization of the software used for this experiment is shown in Figure 2.

Actions

For this experiment, a selective set of actions were implemented. At initialization, characters attempt to reach the goal area, queuing in the process as necessary. As anger increases, characters exhibit increased amount of threatening behaviors as well as approach to the compound. As fear increases, characters are more likely to flee; two levels of fleeing were implemented, one associated with extreme level of fear and one associated with lower fear levels. In the former case, fleeing takes place in random directions away from the control forces. In the later case, fleeing utilizes specific routes, simulating a somewhat more organized retreat. The actions available to the entities and the entities’ state change in response to stimuli were determined by the character behavioral parameter instances.

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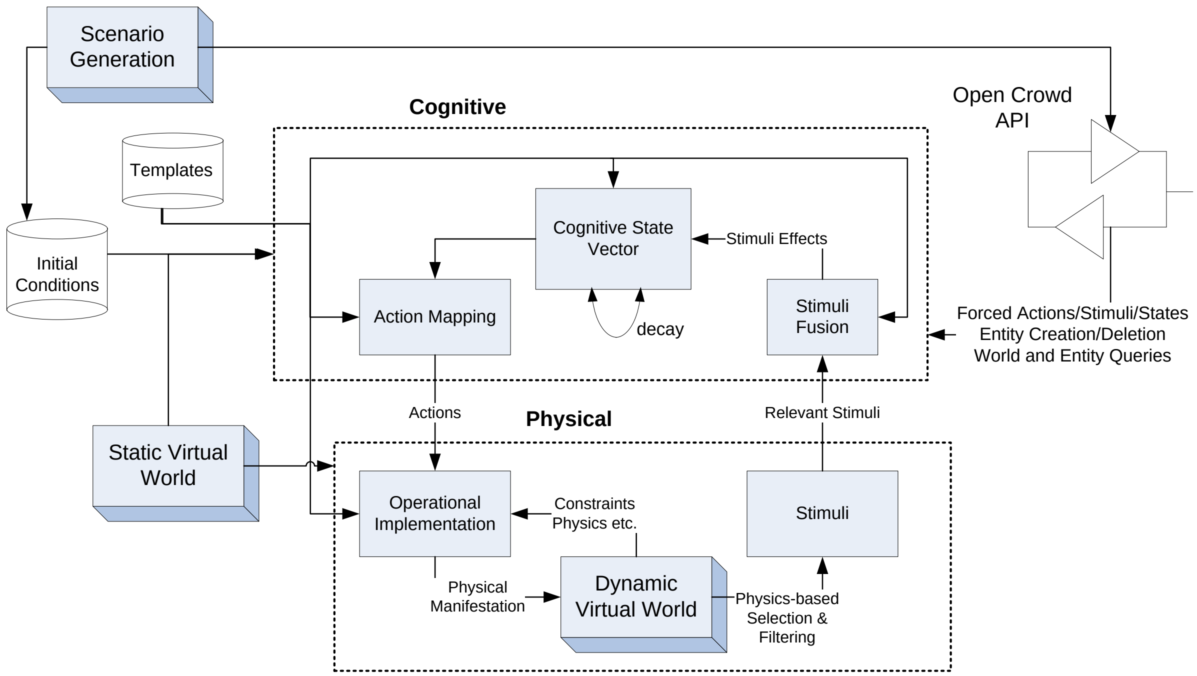

Figure 2. Software Organization for JCF

TESTBED DESIGN

DIS Interface

Initially, design of the modeling and simulation interoperability layer was addressed. We decided we wanted to have a dual ability test bed that contained both a low and medium fidelity (Protocol Data Units) PDUs for the NLWs. The lower fidelity PDUs incorporated the traditional fire and detonate PDUs for federates that couldn't handle a higher fidelity PDU. A medium fidelity PDU was designed in accordance with SISO's IEEE DIS Product Development Group.

According to the SISO IEEE DIS Product Development Group, there is a need to introduce a medium fidelity directed energy event as a PDU. This new DIS standard is still going through the IEEE balloting process. Fields that are being considered in this PDU are Aperture/Emitter Location (Location of the DE weapon aperture/emitter), Aperture Diameter (Beam diameter at the aperture/emitter), Wavelength (Emission wavelength), Peak Irradiance (Current peak irradiance of emissions), Pulse Repetition Frequency (Current peak PRF of emissions), Pulse Width (Current pulse width of emissions), and Pulse Shape (An enumeration describing pulse shape). The rest of the DE Fire PDU contains a series of variable DE records, which is dependent on whether the DE Fire event is targeted at a specific entity or at an area.

If the target is a specific entity, the additional following data is in the PDU: Target DR Info (Target's location, velocity, and acceleration), Beam Spot Shape (an enumeration describing beam shape), and Beam Spot Cross-Section (Records for the lengths of the semi-major and semi-minor axis of the irradiance region ellipse and orientation angle).

If the target is an area, the additional following data is in the PDU: Beam Antenna Pattern (Direction, pattern, polarization of radiation from each *n* beam), and Target Energy (For each *n* target in the area, this record contains the peak irradiance).

In addition to the to the DE Event PDU, another PDU needed to be introduced to handle the damage status from a DE Event, hence, the creation of the Entity Damage Status PDU. This PDU is used to communicate detailed damage information sustained by an entity, which contains a series of records detailing various damage states.

The DE shot sequence can now be defined as the follows. First, is the DE Fire PDU, the on state. This PDU is sent once when the DE weapon is initially fired. Second, is the Entity Damage State PDU, reflecting

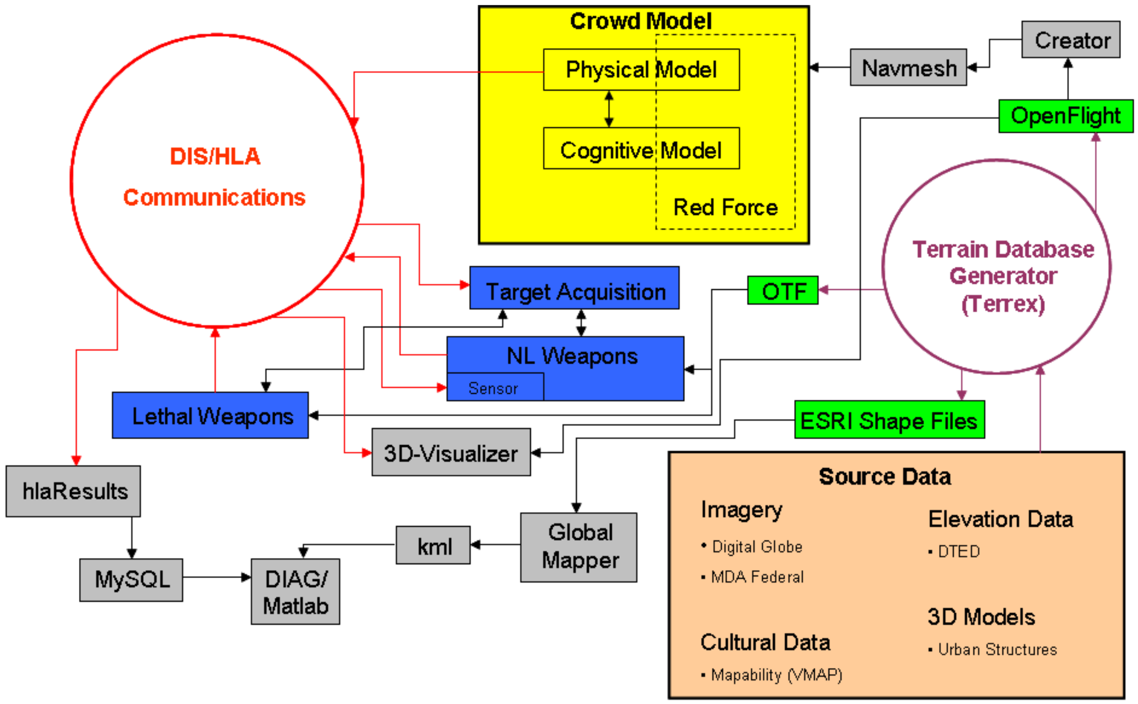

Figure 3. Simulation Configuration

damage. The target(s) will reflect any damage occurred during the engagement by issuing this PDU. Third, is the Entity Damage State PDU, again reflecting damage. As the DE event occurs, the target(s) will continue to update their damage status with this PDU. Fourth, is the DE Fire PDU, the off state. This PDU is sent again at the end of the engagement. Fifth, is the Entity Damage State PDU, reflecting damage. This PDU is a final damage status PDU that is sent by the target(s). Even though these PDUs are in draft status and we made some progress in development of them, we decided to use the low fidelity fire and detonate PDUs with JCATS and OneSAF.

During this project, basic reactions to non-lethal weapons (both kinetic munitions and DEWs) and other stimuli were improved, and a custom DIS PDU to enable JCF to expose information about the internal states and behaviors of the crowd members was developed. These were used to enable the assessment of the experiment on selected metrics. Custom PDUs were developed for the desired NLWs to which crowd entities had distinct reactions. This capability was demonstrated through a federation using JCATS or OneSAF as the SAF. We were able to expose the position / orientation / velocity POV state data of individual crowd members. Further, through a custom Entity State Behavior PDU we were able to expose internal emotional and physical state data attributes on individual crowd members, which were then aggregated through custom data analysis tools to enable external measurement data capture and visualization of internal model state representation.

Figure 3 shows the simulation configuration for the test bed including data sources to develop an urban scenario to generate terrain for the SAFs, crowd model, 3D-Visualizer, DIAG, and MATLAB®, which enabled a correlated database to work with to do experimentation and analysis.

Measures of effectiveness

Metrics were a key component to this test bed for data analysis and assessment. We found that metrics can be cluttered when all crowd entities are displayed in a single graph. As a result, creative displays were created to look at single entities or subgroups of emotional or physical states. Two main tools were used for measures of effectiveness: Raytheon's Data Instrumentation and Analysis GUI (DIAG) and MATLAB®.

DIAG allows a user to compute and display metrics from a simulation run. DIAG can use data from

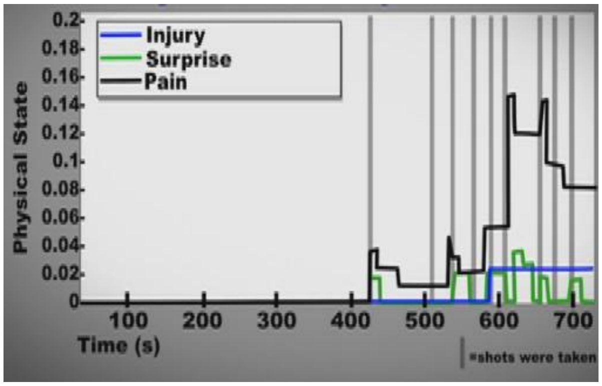

Figure 4. Baghdad Results for Physical States

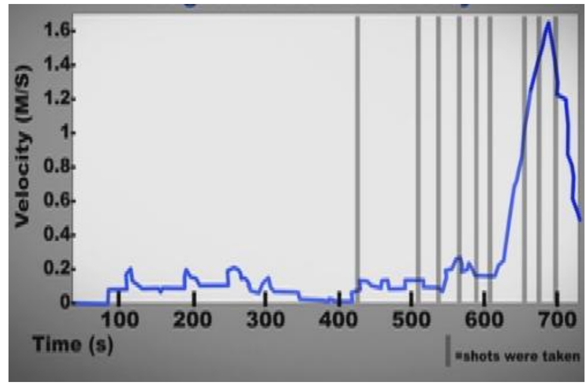

Figure 5. Baghdad Results for Average Velocity

Multiple sources, and be saved as either a plot or a table of values. The metrics can be compared and various trend lines can be computed. Optional constraints can also be applied such as selecting the data for a single entity or for a specific window of time. In MATLAB®, a 2D grid was created, ignoring elevation to approximate distances using lat/long information from the simulation.

For this test bed, during a simulation run, data is captured using hlaResults, which saves the data in a MySQL database. DIAG and MATLAB® pull the data from MySQL to display. A 2D lay down of the buildings, barriers, and fences in the scenario is pulled in from a kml file. There are several displays that can be viewed in DIAG, such as, Shot Range, Crowd Composition, Trajectories, Velocity, Injury, Pain, Surprise, Fear, Anger, Joy (emotional excitement), Actions, Crowd States, Fire location, or Crowd Location.

RESULTS

Figure 4 through Figure 6 all contain simulation results from a Baghdad scenario. The scenario featured an entry control point in Baghdad where middle-aged men were outside the control point walking in to apply for jobs. The crowd begins to get angry as jobs run out and angrier when jobs have been completely filled. Non-lethal weapons are employed to control the crowd. The vertical lines in each graph represent when shots were fired. Figure 4 displays average injury, surprise, and pain versus time. In Figure 5 are simulation results that display the average velocity versus time. The peak in this graph occurs after several entities have been hit with a DEW which caused several entities to flee increasing the average velocity of the crowd.

In Figure 6 are simulation results that display the percentage of crowd for various actions, such as, laying down, seeking to (neutral), seeking to (aggressive), fleeing from, yelling (aggressive), waving hands (aggressive), throwing objects, hiding, and escaping all versus time.

FUTURE WORK

Further development of the tool is difficult without access to the source code for JCATS. This difficulty is made worse by JCATS being a man-in-the-loop tool. However, in OneSAF it would be desirable to develop the interoperability side of the source code to consume the custom PDUs from JCF. This would allow development of a target acquisition algorithm for Monte Carlo simulations. It is also desirable to implement the custom PDUs for the DEWs that were defined, rather than using the traditional fire and detonate PDUs.

With respect to JCF, it is desirable to improve the model's implementation of the availability of behaviors in response to stimuli and state changes as well as the duration of the selected behaviors. Additionally, improvement to the availability of behaviors in response to stimuli is desirable and a need by the public at large.

AWARD

The Raytheon, WernerAnderson, Inc., and Virginia Modeling, Analysis and Simulation Center team recently won the National Training and Simulation Association (NTSA) M&S Award for Outstanding Achievement in Analysis and is featured in this paper.

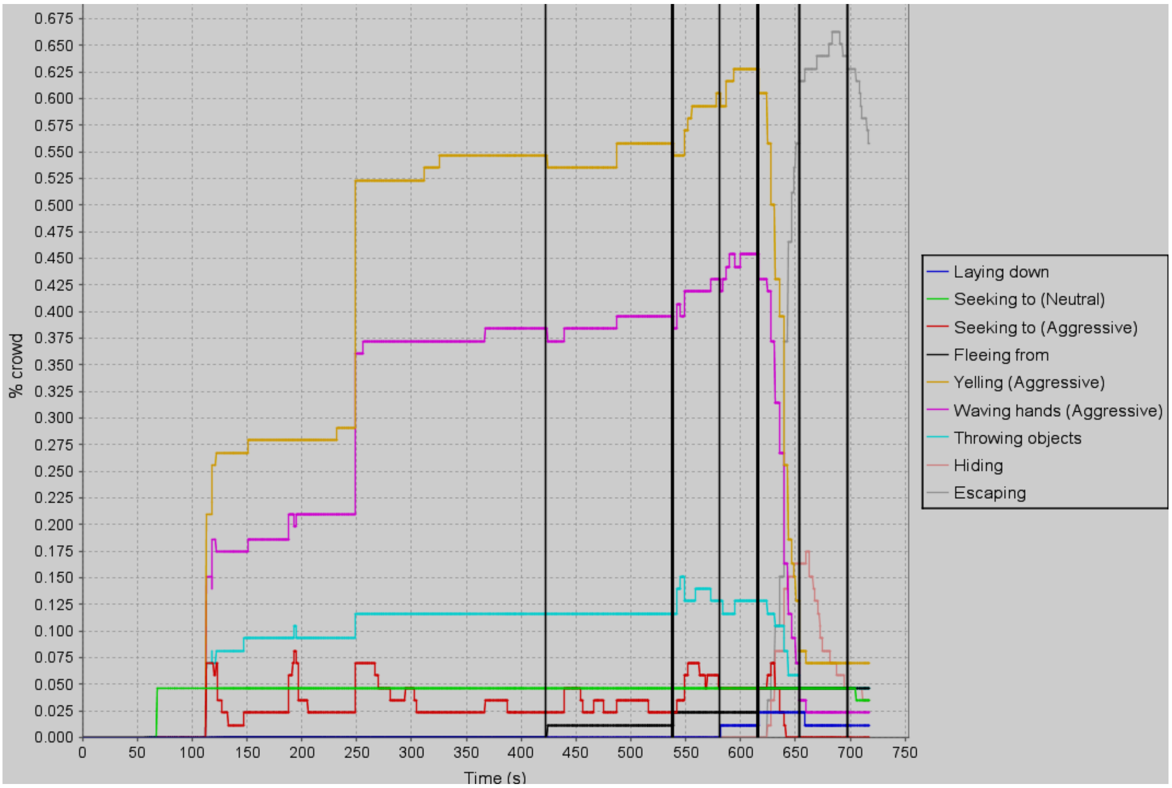

Figure 6. Baghdad Results for Percentage of Crowd Actions Vs Time

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