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Artificial intelligence agents for crowd simulation in an immersive environment for emergency response

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Abstract

Virtual crowds for non-combative environments play an important role in modern military operations and often create complications for the combatant forces involved. To address this problem, we are developing crowd simulation capable of generating crowds of non-combative civilians that exhibit a variety of individual and group behaviors at a different level of fidelity. Commercial game technology is used for creating an experimental setup to model an urban megacity environment and the physical behaviors of human characters that make up the crowd. The main objective of this work is to verify the feasibility of designing a collaborative virtual environment (CVE) and its usability for training security agents to respond to emergency situations like active shooter events, bomb blasts, fire and smoke. We present a hybrid (human-artificial) platform where experiments for disaster response can be performed in CVE by including AI agents and User-controlled agents. AI agents are computer controlled agents to include behaviors such as hostile agents, non-hostile agents, leader following agents, goal following agents, selfish agents, and fuzzy agents. User-controlled agents are autonomous agents for specific situation roles such as police officer, medic, firefighter, and swat official. The novelty of our work lies in modeling behaviors for AI agents or computer-controlled agents so that they can interact with user-controlled agents in an immersive training environment for emergency response and decision making. The hybrid platform aids in creating an experimental setup to study human behavior in a megacity for emergency response, decision-making strategies, and what-if scenarios.

1. Introduction

There has been an increasing interest in conducting emergency response training in virtual reality by including artificial agents with simple and complex rules that emulate human behavior by using artificial intelligence (AI). Modeling such an environment is very critical these days to respond to emergency situations like active shooter events, bomb blasts, fire and smoke. To model human behavior and include human beings and their intelligence is a real challenge. We present a hybrid (human-artificial) platform where experiments for disaster response can be performed by including 1) AI agents: These are computer controlled agents shown in Virtual Reality (VR) to include behaviors such as hostile agents, non-hostile agents, leader following agents, goal following agents, selfish agents, and fuzzy agents, and 2) User-controlled agents: These are autonomous agents involving real human beings exposed to specific situations roles such as police officer, medic, firefighter, and swat official. The AI agents form a closed-loop of real behaviors, which can be used to study real society. This paper describes a design of a collaborative virtual environment (CVE) for training security agents in a megacity for emergency response, decision-making strategies, and what-if scenarios. Our proposed environment offers the flexibility to run multiple training and decision making scenarios for evacuation drills and emergency response. Figure 1 shows a fully immersive user controlled firefighter agent using oculus rift and touch controllers to operate the water hose to put off the fire.

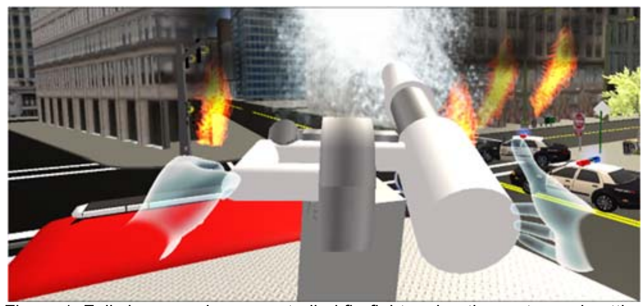

Figure 1. Fully immersed user-controlled firefighter shooting water and putting out the fire in the Megacity VR environment.

Virtual reality (VR) has gained its importance in giving users an exceptional sense of presence in virtual environments. Though VR has existed for several decades, with recent technological advancements and reachability to people, it has become more popular. Disasters like fire accidents, active shooting incidents, bomb blasts, etc. have resulted in the loss of lives and resulted in injuries. As we cannot predict when and where these incidents happen, it is very important to have people trained in emergency evacuation methods and procedures. Proper training and knowledge on how to evacuate and having an escape plan during emergency situations could decrease or even avoid loss of lives or injuries. Despite being effective, these evacuation drills are costly. Usually, the evacuation drills are scheduled because of the need for availability of people. As these are not really performed on the entire sample size of the population, remaining people are unaware of the evacuation rules. With VR comes the flexibility to the users to experience the immersion in a simulated virtual environment and perform evacuation drills at their convenience.

Collaborative virtual environment (CVE) is medium where users can immerse themselves completely in the environment and with the help of VR hardware they can move and interact with the objects in the scene. With this ability, it is possible to train emergency response officials like police, fireman, military officers, and medics. Communication between the officials and people is very critical for safe evacuation. This communication can be simulated in a VR environment with the use of today's virtual reality technologies such as the Oculus Touch. With Oculus Touch's realistic hand/finger tracking, touch sensitive controllers, and controller joysticks users can interact in fully immersive environments. This paper presents a fully immersive CVE communication system that is built for a simulation of a megacity VR environment. The users in this environment can interact with one another and interact with artificial intelligence (AI) agents through the use of Oculus Touch hardware. Figure 2 shows a user-controlled firefighter agent preparing to extinguish the fire through the use of Oculus Rift and touch controllers.

Figure 2. a user controller firefighter can be seen preparing to extinguish the fire while an officer controls a crowd beyond the fire.

Emergency personnel and staff should have an understanding of the response plan and how to lead or direct facility occupants to the nearest evacuation routes (run) and identified secure areas (hide). There is a need to train staff to overcome denial and to respond immediately. For example, training staff to recognize the sounds of danger, act, and forcefully communicate the danger and necessary action (e.g., "Gun! Get out!"). In addition, those closest to the public address or other communications system, or who are otherwise able to alert others, should communicate the danger and necessary action. Internal communication with those in the immediate situation is critical [1]. VR can be utilized to assess and analyze the small details in communication such as how to advise users to deal with the different personality types of civilians in the midst of disaster, how much time should be taken to perform certain tasks, the order in which tasks should be performed, and when the task or tasks should be performed. In addition, with the use of VR, all of these training tactics could be performed in each individual user's personal environment. No money has to be spent on real-life materials, and no real life materials have to be damaged in order to simulate a disaster event. Interactive life-size objects in the VR environment help users get a feel for what interacting with the objects in real life would feel like. For example, if users in the VR environment communicates with their team, and the team all agrees on an appropriate time to get to a fire truck to put out fires, the users in the environment can get to their trucks, and start putting out fire at the agreed upon locations when the environment becomes safe and clear enough to do so. Each emergency response department would have an opportunity to perform its respective protocols, and interactive life size objects in the VR environment help users get a feel for what interacting with the objects in real life is like.

Each emergency response department would have an opportunity to perform their respective protocols, formations, and techniques. As stated in [2], each emergency response department should do the following: 1. Develop a comprehensive training program within the organization to commit stakeholders and employees to improve security and safety, conduct organizational assessments, and prepare to take action in the event of an active shooter 2. At a minimum, yearly exercises should be conducted to test the effectiveness of all active shooter policies and procedures while evaluating the procedural competency of building occupants. With this proposed CVE, there is a focus on the details, realism, and simulation of communication during a disaster event. AI agents respond to user-controlled agents according to their programmed individual behavior. Generally, people in building fires act rationally and altruistically rather than being panic-stricken [4]. This brings a level of realism to the communication in the VR environment and the analysis of the communication. This paper aims toward aiding emergency response officials and civilians in the strengthening of the communication protocol in disasters such as megacity emergency response with multiple bomb blasts, and single or multiple active shooter scenarios.

2. Related Work

Understanding human behavior during an evacuation in building fires can be used to improve evacuation models and their accuracy in simulating fire events [3]. Data and theory of evacuation models that make assumptions about occupant behavior during evacuations can produce unrealistic and inaccurate results. People's stress levels increase when they are engaged in information seeking actions, especially when cues are ambiguous and inconsistent [4] as they are in an unfamiliar situation. In the early stages of a disaster, people mainly rely on their individual decisions and people in their vicinity. People's behavior at this stage is crucial for escaping disaster and surviving [5, 6]. The human response to emergency notification and messaging in a building is enhanced by using technology-based warning or messaging systems [7]. The goal of the technology-based warning system is to alert the occupants with critical information through audible, tactile, or visual means. During emergency evacuation events, human factors also play an important role in the effective outcome of evacuations [8]. Rescue officers need to have a plan to properly direct people to safe zones. Musse et al. [9-11] have developed the ViCrowd system to automatically generate human crowd behaviors based on group behavior instead of individual behavior. They have presented three different ways for controlling crowd behavior: programmed behavior, reactive behavior, and guided behavior. Our proposed CVE follows the three ViCrowd strategies of controlling the crowd behavior: 1) multilevel hierarchy behavior formed by crowd, groups, and agents; 2) rule-based behaviors or reactive behaviors, such as scripted and interactive control; and 3) group-based behaviors in which agents are simple structures and the groups are complex structures.

Arango et al. [12] have further explained that in real emergencies involving multi-users, high-stress situations may not follow the previously trained behaviors in a virtual environment. Such environments are able to encourage learning by leveraging the power of web technologies and the familiarity of the learners to video game technology. Crossland [13] reiterated that emergency training could be useful in reducing the stress and making emergency staff members perform their work better. According to Kuligowski et al. [14], all officers who would be called upon to respond to an active shooter incident should receive training in critical tasks, such as assessment of an active shooter scene, room entry techniques, recognition of explosive devices, and the roles of contact teams, evacuation, and perimeter teams. In addition, officers should receive training in basic emergency medical care techniques that can save lives in an active shooter event, especially with regard to controlling bleeding, maintaining airways, and immobilizing fractured limbs. Experienced police chiefs and other experts strongly recommend that police agencies also conduct advanced training for active shooter incidents that includes multiuser trainings, tabletop exercises, and realistic training in the use of firearms in an active shooter incident.

Advanced training for emergencies situations should be conducted in schools, shopping malls, large industrial centers, churches, hospitals, and other locations for safety and legal issues. Such training can teach officers how to utilize the security assets that may be available in various locations. For example, at a shopping mall, the closing of security gates at individual stores can help to deny the shooter access to many potential victims, and some security devices may be operated remotely. Issues such as radio interoperability should be tested in training that simulates the stressful environment of an active shooting incident, because officers may not comprehend dispatchers telling them to switch their radios to certain channels. Because active shooter situations usually involve multi-agency response, police agencies should strive for consistent policies, strategies, tactics, terms, prohibitions, training, coordination, and radio channels/communications systems on a regional basis [15]. In its simplest form, strategic communication in disasters and catastrophes serves several purposes: first, prior to the event, it can serve to manage the expectations of the public regarding the capabilities and potential assistance provided at all levels of government; second it provides public information prior to and during the event to facilitate the safety and security; and finally, it can, if proactively and effectively used in conjunction with visible ongoing relief efforts, serve to increase the credibility of government and serve as a calming influence to the citizenry [16] .

Immersive CVE have experientially reported helping learners achieve learning outcomes. Participants' self-report that these environments are realistic and not difficult to use. Qualitative studies should be conducted which continue to describe the experience of those following immersive CVEs. Specific questions need to be addressed on how participants would describe the experience of virtual disaster training that includes immersion, reality, and the ability to navigate within the environment. The current studies involve a wide range of delivery systems including total immersion in a cave virtual environment to a simple desktop environment using monitor and mouse interaction. All of these studies use a different method to deliver the immersive CVE [17].

A technologically-based approach for disaster preparedness through Virtual Reality (VR) environments appears promising as it bridges the gaps of other currently established training formats. Many studies have explored the process of learning and its effectiveness in training and education. We believe that immersive VR through Oculus Rift HMD (Head- Mounted Display) will allow a constructivist way of learning where people gain knowledge and experience while interacting with other people through a cloud in a virtual environment. A VR-based training simulation built with haptic (touch) interfacing was implemented by Cha et al. [18]. Mitzushina et al. [19] built a system that combined Oculus Rift with a haptic racket, fusing immersion with haptic interfacing. In that system, when the user hits the badminton shuttle in a virtual badminton game, the racket produces haptic feedback to the user. When the system was demonstrated, it gave users a sense of interaction along with the shuttle's impact.

Sharma et al. [20-22] have used VR as a tool for training and education. They have also used immersive collaborative virtual environments for conducting virtual evacuation drills for subway evacuation [23], university campus evacuation [24], megacities [25], and Virtual City [26] disaster preparedness and emergency response training. Predicting a person's behavior in an emergency situation is very hard as it involves making quick decisions in response to emotional behavior, crowd behavior, level, and type of emergency.

3. Immersive Collaborative Virtual Environment

An immersive environment provides a platform for users to interact with a virtual environment. The collaborative virtual environment is designed using 3DS Max, Sketch Up and programmed with a Unity 3D gaming platform. The cloud connectivity offers multiple benefits. Users can connect themselves using the client avatar. The collaborative virtual environment can be used either in immersive and non-immersive ways. The immersive environment is designed for users to perceive themselves as present in the CVE. A user is required to wear an Oculus Rift head-mounted display to experience the immersive environment. Figure 3 shows a user-controlled agent entering the CVE as a soldier with a gun in hand.

Figure 3.A user wearing HMD and acting as a soldier in CVE

A non-immersive environment is a desktop application that uses a computer, keyboard, and mouse to navigate in the CVE. The CVE can be used to train individual bodies like people, police, firefighters, and medics with respect to emergency situations. The virtual environment is a platform to study human behavior during emergency scenarios, decision-making strategies and what-if scenarios. To give users a realistic feel, the environment contains threats like gunmen and critical accidents like fire, smoke and biohazards. In real-world scenarios, response to such emergency situations is different from person to person. Taking that into consideration, CVE is programmed to have two types of crowd behavior in agents. One is by pre-defining the rules in agents (AI controlled agents) another is operated by users (User-controlled agents) with keyboard and mouse or with VR head-mounted display. Photon cloud networking enables users to connect to CVE over the internet, thus gives the CVE a feature of multiuser interaction over the network. Our approach deals with the interaction between user controlled agents and AI agents to conduct virtual training and learning for emergency response and decision-making. Moreover, in the proposed environment the AI agents respond to commands given by user-controlled agents within the environment.

3.1 User-Controlled Agents

User-controlled agents are the agents that enable real users to be immersed in the CVE. This feature provides the user the feel of immersing himself in the virtual environment and thereby plays the main role in virtual training. Virtual training is more helpful to certain professionals in society such as policemen, firefighters, medics, and soldiers. Our CVE consists of all these avatars, which are required during an emergency. All the above avatars are user-controlled agents and the user can choose from one of these roles.

Each of the roles has different abilities to rescue crowds. Users who enter the environment as a police officer have the ability to set safe points in the environment for the AI agents to run to. In order to set safe points, the user clicks the left joystick, directs an aim line to where they want the safe point to land, and confirms the safe point with the controller's trigger. Upon confirming the safe point, AI agents who are in the vicinity of the officer will run to that point. The user-controlled officer is able to reset the safe point position whenever the user feels that a different location is safer than the original safe point setting. User-controlled agents can also enter the environment as a policeman, medic, soldier, or fireman. The medic has the ability to heal the hurt and wounded people; the medic user heals the hurt civilians with the trigger on the Oculus Touch controller or using a button on the keyboard in the non-immersive environment. The fireman has the ability to climb the ladder on the back of the fire truck and control the water hose using Oculus Touch. Moreover, the soldier has the ability to shoot the target and take out the active shooter when possible by following the protocol. Users are able to use the GUI (Graphical User Interface) menus inside of the Oculus Touch headset in order to choose their role in the environment, choose the number of AI agents that will be in the simulation, choose where and which threats will occur, and see a simulation summary.

3.2 AI Agents

AI agents are computer-simulated agents. Disaster situations are observed to cause panic, stress, anger and wandering behaviors in a crowd. These behavior levels vary among individuals and it is always unpredictable to specify their reaction in crowds. The CVE has two types of AI agents added to the environment: regular agents and colorful agents. Regular agents have humanlike skin tones and are dressed casually, and AI agents have a color, which determines the agent's personality. These personality traits were programmed using C# programming language to differentiate how the AI agent will communicate with emergency response officers (refer figure 4). The personality traits are as follows: Hostile (Red Agents), Non-Hostile (Green Agents), Leader Following (Blue Agents), Goal Following (Purple Agents), Selfish (Orange Agents), and Fuzzy (Yellow Agents).

3.2.1. Hostile Agents

As the name indicates, the hostile agents tend to oppose the instructions given by user-controlled avatars. Due to their panic behavior, they may cause diversions and distractions for rescue officers. They will display panic through body language and actions such as pushing. These agents' first instinct is to panic and cause disruptions in the environment.

3.2.2. Non-Hostile Agents

Non-Hostile agents are not hostile towards rescue officials or AI agents and will not panic. These agents' primary goal is to trust their own instincts first before trusting emergency response officials. They display a moderate to upper-level example of good communication with emergency response officials and other civilians in a disaster. Unlike Leader following agents, they will not rely on rescue teams' advice. If these agents think they see a better alternative goal, they will move towards that even without emergency response officials.

3.2.3. Leader Following Agents

Leader following agents follow the police officer and are the most cooperative when it comes to communication. These agents have proximity sensors that detect user controlled avatars like police and follow their instruction.

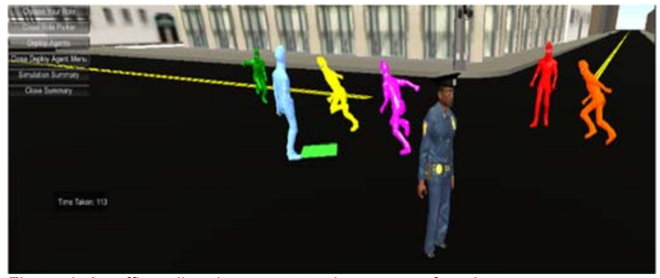

Figure 4. An officer directing agents to the green safe point.

3.2.4. Goal Following Agents

Goal following agents display minimal communication skills as they do not interact much with emergency response officials, their primary focus is to get the goal. These agents are only concerned about where the goal is, and how they can get to the goal. Unlike leader following agents, they will not follow rescue officer but will still reach the goal set by them

3.2.5. Selfish Agents

Selfish agents are deceptive and will use physical communication such as gestures to direct users to the wrong direction in hopes of creating a less populated path for themselves to the safe zone. These agents are not hostile, but following their instruction is not beneficial. These agents' primary focus is to get to the safest place possible themselves without being accompanied by others. Selfish agents are not concerned with the safety of others, and as long as they themselves are safe, their goal is met.

3.2.6. Fuzzy Agents

Fuzzy agents communicate minimally with emergency response agents and operate based on their feelings. These agents' speed to the exit is based on their levels of stress, panic, and anger. If the fuzzy agent has a high level of stress, a medium level of panic, and a medium level of anger, their speed will be much slower than a fuzzy agent with low stress, low panic, and low anger. The best case scenario for a fuzzy agent is for the fuzzy agent to have low stress, low panic, and low anger. The worst case scenario is a for a fuzzy agent to have high stress, high panic, and high anger.

3.3 User to User Communication

User to User communication happens through Photon cloud networking. The VR communication system allows users to communicate with other users through their respective user-controlled avatars, and chat to act out the protocol and communicate textually.

Figure 5. Medic pointing to where help is needed.

The GUI Menus inside of the Oculus Touch headset, notify users when a task is accomplished and when new objectives are set. Lastly, emergency response agents can control and use objects in the environment in order to carry out tasks, missions, and protocols. In order to use these controls, users will utilize the Oculus Touch hardware in order to navigate the environment, and use the objects in the environment with Oculus Touch's controllers. Figure 5 shows the medic pointing towards a civilian who is injured. As seen from figure 5, the hand appears when the user is using Oculus rift controllers in both the hands.

3.3 User Controlled Agents and Object Interaction

As mentioned earlier, user-controlled agents can enter the environment as a police officer, medic, soldier, or fireman. These different roles each include their own respective abilities and responsibilities. The police officer has the ability to set safe zones and escort people to safety zones as well as drive the police vehicle. The medic has the ability to heal hurt and wounded people with the trigger on the Oculus Touch controller. Whereas the fireman has the ability to climb the ladder on the back of the fire truck and control the water hose according to a defined protocol. Moreover, the soldier has the ability to take out the active shooter when required.

4. Development and Implementation of CVE and Communication System

Megacity's communication system was developed in the coding language C#. The system is implemented through a series of script assignments based on the personalities of the AI avatars in the environment. The object grabbing and climbing capabilities are implemented using the VRTK (virtual reality took kit). The events like climbing the ladder by firefighter, picking up the rifle needed to shoot the active shooter target by a soldier, turning on water from fire hose turret on top of the fire truck are developed using toolkit.

4.1 Phase 1: Modeling

Phase 1 of the Megacity communication system consisted of modeling the environment. Initially, the city environment was taken from Google Sketch-up, and cosmetic changes were made to make its appearance closer to a real city block and give the user a better sense of presence when in the environment. These cosmetic changes include the following when the environment was imported from Sketch-Up into Unity 3D: road lines, grass, a sun, street signs, trash cans, benches, fences, statues, rocked paths, fire, smoke. Moreover, there have been three types of scenarios modeled, a gunman threat, bomb threat, and a biohazard threat. We added street lights and sirens to the CVE utilizing C# coding.

4.2 Phase 2: Exporting to Unity 3D and Photon Cloud Setup

In phase 2, the environment was exported from Google Sketch-up and imported into Unity 3D. Later, the following additions were made: added 3D humanoid models, vehicles, and functionality with C# code. First, Unity 3D's tools for animating avatars were utilized in order to give each agent in the environment functionalities necessary to navigate the environment. These functionalities include walking, running, and jumping. Moreover, multiple C# scripts were added to the avatars in order to give the avatars the ability to make decisions based on their personalities. In addition to that, C# scripts were added to the user-controlled agents in order to give users the ability to communicate with AI agents and control objects in the environment. Likewise, C# scripts were used to add functionality for a Photon server/client networking system that allows multiple users to collaborate and communicate with one another.

4.3 Phase 3: Oculus integration and controller hand simulation

With the use of Oculus Rift and the Oculus Touch controllers, users are able to navigate the environment and interact with objects. The Oculus Touch headset allows users to navigate and experience the environment with full immersion. With the headset, the user is able to look around with 360-degree vision. Oculus Touch controllers also give haptic feedback to the user when using objects such as guns and water shooters.

5. Results and Future Work

The objective of this work is to provide a CVE that serves as a platform where evacuation drills and training can be performed virtually for emergency response situations in a city environment. This approach is identified as cost-effective and convenient. The ability of multiple users to immerse in VE and interact with one another and computer agents, train users on how to respond and to have a solution for what-if scenarios. Photon cloud was tested with a size of ten clients running at the same time. The look and feel of the environment are more realistic with streetlights, traffic signals, proper city environment. Fire and smoke gave the feel of a disaster situation. Using Oculus Rift, users are able to immerse themselves and communicate with one another. They are able to turn around 360 degrees. The AI agents can be observed with different behaviors following the rules implemented for each type. Through this collaborative virtual environment, emergency rescue officials can be trained on how to carry out safe procedures and perform drills. People emotions like stress, panic anger can be triggered in CVE using fire, smoke or active shooter. As it is not possible to arrange the disaster setting in real-time for evacuation drills, one can use this for training purposes. Thus, we get valuable information about human behavior, their response and decision-making. From our current observations, while testing, individuals happen to execute different responses and decision making with each test. The further scope of this would be to apply the test to a larger group in a CVE.

6. Conclusions

Our proposed CVE can be used for training security agents to conduct emergency response training in VR by including artificial agents with simple and complex rules that emulated human behavior by using AI. We have presented a hybrid (human-artificial) platform where experiments for disaster response can be conducted using computer controlled (AI) agents and user-controlled agents. We hope our proposed CVE will help in visualizing emergency evacuation time and what-if scenarios that are difficult to model in real life. It can also act as a training and educational tool for decision-making strategies during an emergency response. We have developed a crowd simulation capable of generating crowds of non-combative civilians that exhibit a variety of individual and group behaviors at a different level of fidelity. The user-controlled agents can enter the CVE environment using Oculus Rift and are able to respond to emergency situations like active shooter events, bomb blasts, fire and smoke. This platform includes AI agents with the following implemented behaviors: Hostile (Red Agents), Non-Hostile (Green Agents), Leader Following (Blue Agents), Goal Following (Purple Agents), Selfish (Orange Agents) and Fuzzy (Yellow Agents). Also, this platform includes user-controlled agents which have roles such as police officer, medic, firefighter, and soldier. The platform can be fully immersive with the use of Oculus Touch, or non- immersive desktop version with the use of mouse and keyboard. We have developed this platform to study human behavior during different what-if scenarios with the hope of mitigating the losses that accompany a disaster.

In conclusion, this CVE system will act as a platform that allows emergency response officers and civilians to communicate with one another in order to carry out tasks to follow protocol in an emergency situation. Unity 3D has been used to develop the collaborative server/client based virtual environment that runs on a cloud. The future work will involve the implementation of more behaviors such as altruistic behavior and family behavior.

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Dr. Jock O. Grynovicki is the chief of the Complex Ground Systems & Operations Branch of the Human Research Engineering Directorate of the Army Research Laboratory (ARL). His background includes numerous field and laboratory studies examining battle command performance and metrics, metrics for command and control systems, virtual systems, and managing Human System Integration programs for the U.S. Army. He has a master's degree in public health policy and doctorate degree in statistics. He is currently the ARL lead research and application coordinator for Soldier Modeling and Simulation Tools Development, Soldier Centered Analysis for the Future, and Social Cultural Analysis at ARL HRED.

Dr. Peter J. Grazaitis has worked at the U.S. Army Research Laboratory's Human Research and Engineering Directorate (HRED) for over 30 years and has worked to advance Army logistics and field logistics planning systems for much of his career. He has assisted with fielding various logistics programs for ammunition, petroluem, water, and other logistical commodities for the Combined Arms Support Command. Mr. Grazaitis has also recently received the prestigious Tibbets Award for his numerous Small Business Innovative Research (SBIR) work in promoting innovative technologies. He is now the manager of the human dimension area of the Dense Urban Environment program at HRED.