Technical Report 1139

Predicting Rapid Decision-Making Processes Required by the Dismounted Objective Force Warrior

Eliza Beth Littleton and Jared T. Freeman
Aptima, Inc.

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United States Army Research Institute for the Behavioral and Social Sciences

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ZITA M. SIMUTIS
Director

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Technical Review by

Robert E. Solick, ARI
Scott A. Beal, ARI

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14. ABSTRACT *(Maximum 200 words)*:

This report was developed under a Small Business Innovation Research Program, Phase I. The technology of the Objective Force Warrior (OFW), though still in the conceptual stage, promises to revolutionize warfare by providing information in unprecedented volume, particularly about the locations of threats and other human participants. Ensuring that Soldiers employ OFW technologies well may require a second revolution that focuses on training decision-making skills of warfighters. Predicting the effects of conceptual OFW technologies on decision makers is challenging. This research addresses this problem by laying the groundwork for a simulator that will accommodate a full research program—from discovering and validating requirements to building training—and enable the Army to observe future technology effects. The work triangulated a series of methods—knowledge elicitation methods, analyses, and exercises on a simulation test bed—to systematically examine and test hypotheses concerning decision making with future battle technologies. Our exercise of the test bed suggests there will be positive effects of the technology, as well as unintended negative effects. For example, we observed that threat-sensing technology simulated in this test bed simplified and focused the operation, but may have lulled players into a false sense of confidence in the technology's capabilities.

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Eliza Beth Littleton and Jared T. Freeman
Aptima, Inc.

Infantry Forces Research Unit
Scott E. Graham, Chief

United States Army Research Institute for the Behavioral and Social Sciences
5001 Eisenhower Avenue, Alexandria, VA 22333-5600

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FOREWORD

The Infantry Forces Research Unit of the U. S. Army Research Institute for the Behavioral and Social Sciences is conducting research to develop training methods that will permit small unit leaders to perform effectively in the context of emerging Future Force concepts and technologies. The Objective Force Warrior (OFW) concepts exploit the enormous opportunities made possible by our capacity to gather, organize, and distribute battlespace information electronically. Advanced information systems will be developed and fielded to process and display critical data available from multiple sensor and database systems. This marks a revolution in warfare technology. However, ensuring that Soldiers employ OFW technologies well may require a second revolution, one that focuses on training the tactical decision-making skills of warfighters, particularly leaders, in this new technology environment. To achieve this training revolution, the Army needs a way to predict the decision requirements imposed by future systems and to test training strategies that help Soldiers use OFW technology to best advantage.

This report describes the approach and results of an Army Phase I Small Business Innovation Research project that addressed these challenges. The project developed a hybrid expert-interview and analysis method for identifying future decision and training requirements, and for developing a simulation in which to observe the impact of future OFW technologies on leaders' tactical decision making. This research produced an initial version of this simulation. It is intended to be a tool that will accommodate a full research program—from exploring and discovering new decision requirements to validating them, building training for them, and validating that training. In addition, this research produced empirical data using the simulator that reveal some surprising and not entirely welcome effects of new technology, effects that must be managed with new training for the OFW.

The results of this research have been discussed with U.S. Army Infantry School Directorate of Operations and Training.

FRANKLIN L. MOSES
Acting Technical Director

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Aptima and its teammates (Alex Kirlik of the University of Illinois, and Norm Blankenbeckler and his colleagues at Northrop Grumman Missile Systems) are grateful to Richard E. Christ and Scott E. Graham of the Army Research Institute, who directed our team towards this important topic, supported the work reported here, and offered valuable critiques.

PREDICTING RAPID DECISION-MAKING PROCESSES REQUIRED BY THE DISMOUNTED OBJECTIVE FORCE WARRIOR

EXECUTIVE SUMMARY

Research Requirement:

The technology of the Objective Force Warrior (OFW), though still in the conceptual stage, promises to revolutionize dismounted warfare by providing information in unprecedented volume, particularly about the locations of threats and other human participants (both combatants and noncombatants). These claims are bold and encouraging, but they are not fact; they are predictions. A method is needed to test these predictions or, more generally, to explore the impact of these technologies on the decision making of warfighters. If these technologies fulfill their promises, we will be witnessing a revolution in warfighting. However, ensuring that Soldiers employ OFW technologies may require a second revolution, one that focuses on training the decision-making skills of warfighters, particularly leaders.

To achieve this training revolution, the Army needs a way to predict the decision requirements imposed by future systems. This is challenging because human and machine form a closed loop; introducing new technology may change how Soldiers make decisions, and what decisions they make and why. Thus, the introduction of innovative electronic information systems may change decision making and the decision-making skills required of OFWs (relative to Soldiers in the current technology environment). It is necessary to prepare and train leaders in advance of receiving the new technologies—meaning that training redevelopment needs to happen now.

Procedure:

The over-arching goal of the current research is to discover and test how the leaders of military operations in urban terrain (MOUT)—missions conducted by dismounted, small-unit, light infantry—will make decisions using the tactical information supplied to them by future Objective Force technologies. However, these OFW technologies have not yet been built and fielded. They are conceptual designs. Simple speculation about their benefits—however rational, systematic, or grounded in theory—cannot substitute for observation. To anticipate how new OFW technology may change decision making, one needs a device in which to simulate the future. The specific goal of the current work was to prototype a simulator that will accommodate a full research program—from exploring and discovering new requirements to validating them, building training to address them, and testing that training. Our work triangulated a series of methods—knowledge elicitation methods, analyses, and exercises on a simulation test bed—to systematically examine, extrapolate, and test hypotheses concerning decision making in a future battlespace. We analyzed interview data to identify specific instances of future-technology impact on MOUT leadership decision-making. The interview results were used to develop simulator requirements, scenario elements, and an initial scenario script. We then developed the initial MOUT test bed from an existing team-in-the-loop simulation system: the Dynamic Distributed Decision-Making simulator. The initial results of using this simulator were collected from an exercise in the simulator in which two of Aptima's operational analysts played the game, one as platoon leader and the other as squad leader.

Findings:

Our exercise of the simulation test bed suggests there will be both positive effects of the technology as well as unintended negative effects. On the one hand, it seemed that the predicted effect of the technology bore out. Specifically, having threat-location data simplifies planning and tactical operations, enables the team to focus on the enemy, and lessens the need to operate reactively and defensively in response to unexpected threats. There is less need for intuitive decision making, and a greater role for analytics. Given a relatively simple array of threats and reliable communications, the threat-sensing technology modeled in this scenario did enable members of the human team to support one another in pushing and pulling information about threats. However, we also observed failures in players' performance that suggest that the threat-sensing technology may also have lulled the players into a false sense of confidence in the abilities of the technology.

Utilization of Findings:

The work described here has a number of benefits for the U.S. Army Research Institute (ARI) and the Army MOUT community. It produced an initial test bed that allows the Army to go beyond interviewing techniques about the future battlespace and study human players directly as they filter information, communicate, and coordinate using simulations of technologies that do not yet exist. It initiated a process for applying empirically grounded knowledge of spatial reasoning, critical thinking, teamwork, and information management to OFW leadership challenges. It revealed and leveraged expert knowledge of MOUT operations and training challenges. Finally, it delivered a method for reading the future decision and training requirements to ARI for its continued use.

If the test bed were further developed it would enable ARI and its partners to explore systematically the effects of proposed technology on decision making, specify the decision requirements imposed on warfighters, develop training, and test it. In short, this body of technique and technology will help the Army to enact a training revolution in parallel with—even in advance of—the OFW technology revolution.

PREDICTING RAPID DECISION-MAKING PROCESSES REQUIRED BY THE DISMOUNTED OBJECTIVE FORCE WARRIOR

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PREDICTING RAPID DECISION-MAKING PROCESSES REQUIRED BY THE DISMOUNTED OBJECTIVE FORCE WARRIOR

Introduction

> Just as the Army learned to own the night instead of fearing it, so also must we own the city. Tomorrow's objective is not the top of a hill; it lies in the middle of a city block, surrounded by noncombatants.
> *LTC Robert R. Leonhard, USA Ret. (Army Magazine, April 2003, p. 44)*

Many argue, pointing to operations from Somalia to Iraq, that the battle of the future is the military operation in urban terrain (MOUT), an operation characterized by rapid decision making in the most challenging battlespace possible. Entering this arena, a dismounted Infantry unit is in an environment that is as rich in sensory data as it is unpredictable, one in which the participants are difficult to classify (as friends, foes, or non-combatants), the geometries of potential assault and escape routes are complex, the enemy's rules of engagement are unfamiliar, progress is slow, and action is rapid. To win in this terrain, platoon and squad leaders are challenged to size up threats and opportunities arrayed in three dimensions around them, plan flexibly, coordinate movements, and communicate complex information effectively.

For example, in one summary of lessons learned by the Army during the Iraq War (LTC Jim Smith, 15 May 2003), particular emphasis is paid to the need in an urban environment for threat-sensing and squad-level communications technologies. Specifically, the author reports the need for sensing humans in buildings up to 300 meters away and the need for lighter radios with better ranges for communicating within the squad, with the platoon leadership, and with platforms from which the Soldier is dismounted.

The technology of the Objective Force Warrior (OFW), though still in the conceptual stage, promises to provide these and other capabilities. If these promises are fulfilled, OFW will revolutionize dismounted warfare by capturing and providing information in unprecedented volume, particularly about the locations of threats, friends, and civilians. It will also address the need for communicating about complex information efficiently and rapidly.

New OFW technology *should* afford the leader the time to plan and the Soldier the ability to close quickly with the enemy and win the battle. However, the claims for OFW are just that. To prove these claims true requires observational research. The outcomes of that research may be surprising. Unexpected, and not always positive, effects of new technology have been observed in research in aviation (MacMillan, Deutsch, & Young, 1997; Sarter & Schroeder, 2001), nuclear power (Mumaw, Roth, Vicente, & Burns, 2000), manufacturing, and other domains, in which the nature of expertise has evolved as information-collection, integration, and decision support technology have been introduced.

A variety of theories have been developed about the nature of the effects of introducing new technologies, among them Hammond's notion that advanced technologies expand decision making requirements from correspondence—getting the right answer—to coherence—getting the answer in the right way (Hammond, 2000; Kirlik & Strauss, 2001; Mosier, 2001). From this viewpoint, human-machine systems are closed-loop systems. New technology may change *which* decisions warfighters make, *when* they make them, *how* (e.g., correspondence vs. coherence) and, to some extent, *why.* Clearly, it is important to build a deep understanding of the cognitive effects of technology on decision makers, an understanding that we believe cannot be achieved through introspection or computational modeling alone. What is needed is observation of the effects—or decision requirements—that technologies impose on decision makers. This, in turn, will enable the Army to develop and evaluate training for OFW leaders in advance of receiving the new technologies. If OFW constitutes a revolution in warfighting technology, OFW training will be an equally important concurrent revolution.

The over-arching goal of the current research is to understand how leaders will need to adjust their decision making in response to the new kinds of information they will have because of future Objective Force technologies. The types of decision making tasks that we have focused on in this project are (a) the *route planning* that needs to happen in order to engage the enemy, find cover, or make the best escape, and (b) the *multi-tasking* that leaders must do to simultaneously eliminate enemies and protect fellow Soldiers and non-combatants. Related to these mission tasks are other tasks at the platoon and squad leadership levels such as sizing up the array of threats, conveying complex information about the battlespace, and coordinating movements.

The main problem confronting the current work is the difficulty of evaluating the effects of technologies that have not yet been developed. Simple speculation—however rational, systematic, or theory-based—cannot substitute for real observation. To anticipate how new OFW technology may change decision making, one needs a device for simulating the future technology environment. One needs a simulator to *hypothesize about,* and then, just as importantly, *validate* potential decision requirements and their implications for training.

The specific objective of the current work was to lay the groundwork for a simulator that will accommodate a full research program—from explorations into new requirements to validating them and building training for them—so that the Army may observe the effects of future technologies on leaders' decision making. The resources and scenarios in such a simulator must support hypothesis testing by representing aspects of technologies that may influence decision making. At the same time, the simulator must support discovery, by allowing researchers to observe emergent effects of technologies. To develop this simulator, one needs to identify MOUT tasks and the future technology concepts with the potential to raise new decision-making issues when leaders apply one to the other in an actual battle scenario. The difficulty of developing such a simulator is illustrated by the number and complexity of questions that were raised as the work progressed. For example, which technologies might cause new problems for the leader? In which specific context of urban missions and tasks would new problems arise? How do we probe for the details of these future issues so that we have enough information to understand the nature of the new decision-making requirements, the productive behaviors, the error-causing behaviors, and the training remedies that will prepare leaders effectively? Although this report cannot answer all of these questions, it details our initial effort to characterize the problems involved and develop an approach for examining them.

Approach

Our work triangulated on this problem using several methods—knowledge elicitation methods, analyses, and exercises on a simulation test bed—to systematically examine, extrapolate, and test hypotheses concerning decision making in a future battlespace. One loop of this spiral development is illustrated in Figure 1 and shows, across the two boxes, two phases of work: (a) the analysis period leading up to the development of the simulator and (b) building and exercising the simulator to validate training and decision requirements.

The first phase of the approach consisted of interviews with subject matter experts (SMEs) and analyses of the results obtained from the interviews to determine the required properties of a simulation test bed. We developed a hybrid interview method to elicit expert information about decision-making challenges in MOUT and the application of future technologies. We interviewed four experienced MOUT instructor/observers from Northrop Grumman Missile Systems and two operational analysts internal to Aptima. The two operational analysts each had over 15 years of experience serving in numerous tactical positions in the U.S. Army. We analyzed the interview data to define the decision requirements or challenges that a scenario must tap, the resources needed by decision makers, scenario features, and a script.

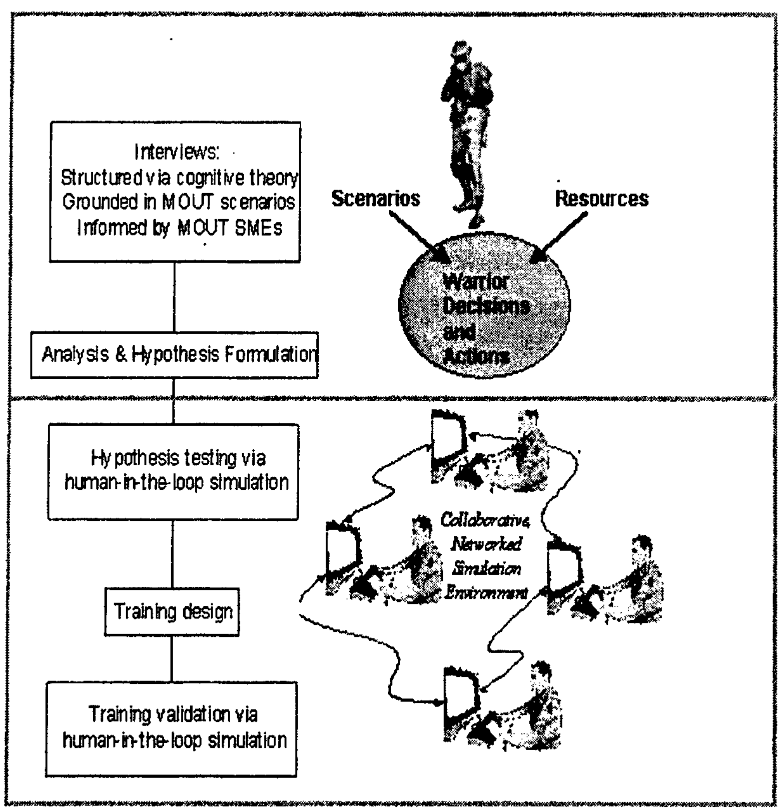

Figure 1. An overview of the approach to the research.

The second phase of the approach was to conduct human-in-the-loop experiments in the simulator to (a) validate the decision requirements, (b) develop training concepts, and (c) validate those training concepts. In the current effort, we began part of this second phase of work by modifying an existing simulator designed for team-in-the-loop decision-making research. We exercised that simulator with the participation of the two of Aptima's operations analysts. The results of the exercise confirmed the necessity of previously identified basic features of the simulation and suggested areas for future development (see Discussion).

Interview and Analysis Phase

The interview method. One of the innovative products of our work was a structured interview method designed to guide experts in projecting into the future. The method is a hybrid that combines aspects of critical incident technique (Flanagan, 1954) in that it is grounded in brief scenarios that are defined by missions and technology suites. It draws on Cognitive Work Analysis (Vicente, 1999) in that it attempts to elicit the multiple goals of warfighters, the opportunities presented by technologies, and the constraints those technologies impose. It is also grounded in a robust theory of technology (Parasuraman, Sheridan, & Wickens, 2000) that supports specification and analysis of decision-aiding systems in the scenarios.

Our hybrid interview method consists of four parts. Part one of the method elicits current knowledge about the relatively unchanging elements of the MOUT environment. We tapped this knowledge using primarily the Critical Incident Technique by asking questions such as the following: What events in MOUT missions and characteristics of the MOUT environment lead to difficulties? What things go wrong? What are critical challenges but hard to train? What are typical blind spots of novice leaders? In part two, we asked our six experts to rank the criticality of these MOUT features and decision challenges. Part three involved generating a matrix that crossed these challenges (in the rows) against future technologies (in the columns; see Table 3). Part four of the interview process guided the SMEs to fill in the cells of the matrix with predictions of the benefits and pitfalls of each technology for each decision challenge. The entries in the cells (particularly the pitfalls of technologies) provide strong guidance concerning the decision requirements per technology.

We drew on Parasuraman et al. (2000) to guide the development and analysis of future technology concepts. Their framework was developed to support design decisions concerning the allocation of information processing and action tasks to humans vs. machines. We used it here to structure the task of predicting human-system failures. In the Parasuraman et al. framework, Stage 1 automation or technology is called Information Acquisition technology. At this level of sophistication, the technology collects and filters environmental information, but does not aid decision making in any other way. Stage 2 automation, called Information Analysis, integrates or fuses this information into more meaningful, task-relevant cues that are made available perceptually to a human via an information display of some type. Stage 3 automation, called Decision Selection, selects action based on a human or machine assessment of the situation. Stage 4 automation, called action implementation, takes action through actuators of various types (e.g., unmanned aerial vehicles) according to the decisions made by Stage 3 systems.

Using the Parasuraman et al. framework, we classified examples of future tactical technologies. Descriptions of the technology concepts were, in part, collected from documents detailing Objective Force technology requirements, technology needs gleaned in the Army's

Lessons Learned from operations in Afghanistan, and other MOUT and OFW articles. However, most of the examples of technology concepts that we gathered represented the two lowest levels of automation—Parasuraman et al.'s "information acquisition" and "analysis" levels. Relatively few represented higher levels of automation such as technologies that select among options or implement them. Aptima generated additional technology concepts at the "decision selection" and "action implementation" levels, so that a full range of automation in decision-aiding technology could be considered. These tactical technologies are defined in Table 1.

Table 1 *Human-Automation Interaction Levels*

Technology class (Parasuraman et al., 2000)	**Description of Tactical Technology**
Information Acquisition	Map-based display that indicates locations of own forces, enemy forces, and non-combatants
Information Analysis	Locates zones of threat and safety (plus above)
Decision Selection	Recommends routes to assault enemy and protect own troops (plus above)
Action Implementation	Issues fragmentary order of route plan, immediate objectives, and required weapons and sensors (plus above)

In Part four of the interview process our six SMEs filled the cells of the matrix by crossing technologies with decision challenges to project how a specific technology would influence a specific MOUT challenge. The resulting data in the cells reflected technology trade-offs: the opportunity a specific technology could have, and the disadvantage it might pose based on how it was used or misused. The disadvantages were usually challenges that could be addressed with training, and in this way, the matrix yielded not only decision, but also potential training requirements.

<u>Interview Data Analysis.</u> Interviews with the SMEs had to be highly structured in order to specify the human-in-the-loop simulation as we have described it here. The methods for eliciting and analyzing insights about technology "trade-offs" and emerging decision challenges were generative enough that they resulted in information to build an initial version of the simulation. Specifically, the methods resulted in two kinds of information: (a) current knowledge about the invariant elements of the MOUT environment, features that characterize this high-tempo, multi-task, high-intensity fight, and (b) projected knowledge about future challenges. In the latter case, the experts were guided to project and predict technology "trade-offs" such as the ways future technology could help, and the ways it could hinder success in a MOUT mission. The results of these analyses are presented in the Results section.

Simulation Building and Testing Phase

Our interview data were rich. However, interview data are never more than a source of hypotheses. Particularly for analyzing high-tempo, high-intensity tasks involving complex problem solving, nothing—including introspection (interview data) and computational models—can replace the need to study the behaviors of real human operators. Since the battlespace we want to observe does not yet exist, and since we need highly systematic, empirical, measurable means of studying human behaviors, we implemented a lightweight simulator with representative

MOUT scenarios. We designed a simulation scenario to test decision requirements we uncovered during the interview process and implemented these in Aptima's Dynamic Distributed Decision-Making (DDD) synthetic task environment. Specifically, this effort produced an initial validation test bed along with a simulation scenario of MOUT tasks and OFW-like technologies. This "envisioned" world is designed to challenge the platoon leader in key aspects of OFW MOUT operations: route planning, information filtering, coordination, and communication. It enables the platoon leader to work with another player in the role of a squad leader. This is a two-player game because our analyses of the interview data suggest that the successful MOUT mission depends greatly on tight coordination and effective communication among platoon and squad leaders. In addition, Aptima's experience is that one must train team skills in teams.

The simulation is designed to represent much of the complexity of the MOUT environment as well as many of the data and data sources in this environment, so that the platoon leader must gather, verify, integrate, and exchange information with the squad leader. Crafting the simulation scenarios required a collaboration of operational experts with DDD programmers who together blended DDD functions and scenario requirements. The discussion and screenshots of the resulting DDD-MOUT are presented in the Results section.

Why the DDD? The DDD is a scaled world that is the product of a team research program that has been underway for over 15 years. The DDD, co-developed by David Kleinman and Daniel Serfaty at the University of Connecticut in the early 1980s (Kleinman & Serfaty, 1989; Kleinman, Pattipati, Luh, & Serfaty, 1992), is a distributed multi-person simulation and software tool for understanding decision making in a dynamic team environment. Successive DDD generations have demonstrated the flexibility of the DDD design in reflecting different domains and scenarios to study realistic and complex military team decision making for command and control. Although many multi-person wargaming simulators exist today (e.g., RESA, JTLS, and MTWS), the DDD is unique in its flexibility. This feature is critical to the current work because the DDD-MOUT simulator needs to be flexible enough to allow one to observe many different effects from the opportunistic application of technologies to MOUT challenges. Most team simulators are built with a task, information, resource, and command structure that replicates a specific military team task. The DDD platform, in contrast, was designed to capture the essential elements of varied command and control decision tasks, and to allow the experimenter to vary the tasks demands imposed on individuals and teams, team structure, access to information, and control of resources (Figure 2).

Because it is rooted in a strong command and control team performance paradigm, the DDD synthetic task environment has provided a substantial degree of experimental control while engaging team players at a low-to-moderate degree of realism in very different environments (compare the national peacekeeping scenario implemented in Figure 2 with the local MOUT operation depicted in Figure 3. The gradual introduction of new technologies into the simulator (e.g., net protocols, multi-media displays, standard military symbology, verbal and electronic communications, realistic force-on-force scenarios, active tactical maps, intelligent agents, and voice recognition and generation) has further increased the degree of realism without affecting the DDD's ability to carefully manipulate a large set of external and internal variables of team performance on decision making tasks.

The DDD scenarios can vary the number, type, uncertainty, and timing of tasks to be processed, as well as their timing, information requirements, and resource requirements, allowing the manipulation of overall decision workload. Organizational structure can be manipulated in the

DDD by changing authority, the ownership and control of assets, the availability of information, the existence and types of communication allowed, and team size.

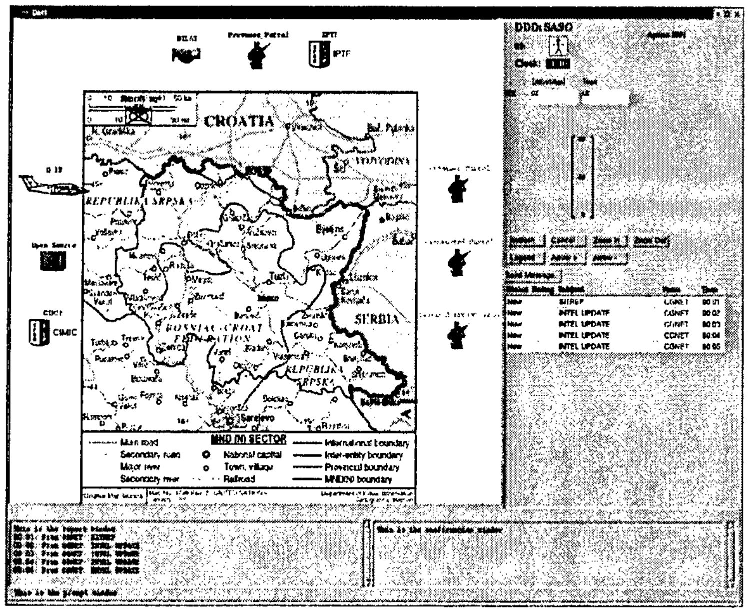

Figure 2. A Bosnian peacekeeping scenario implemented on the DDD.

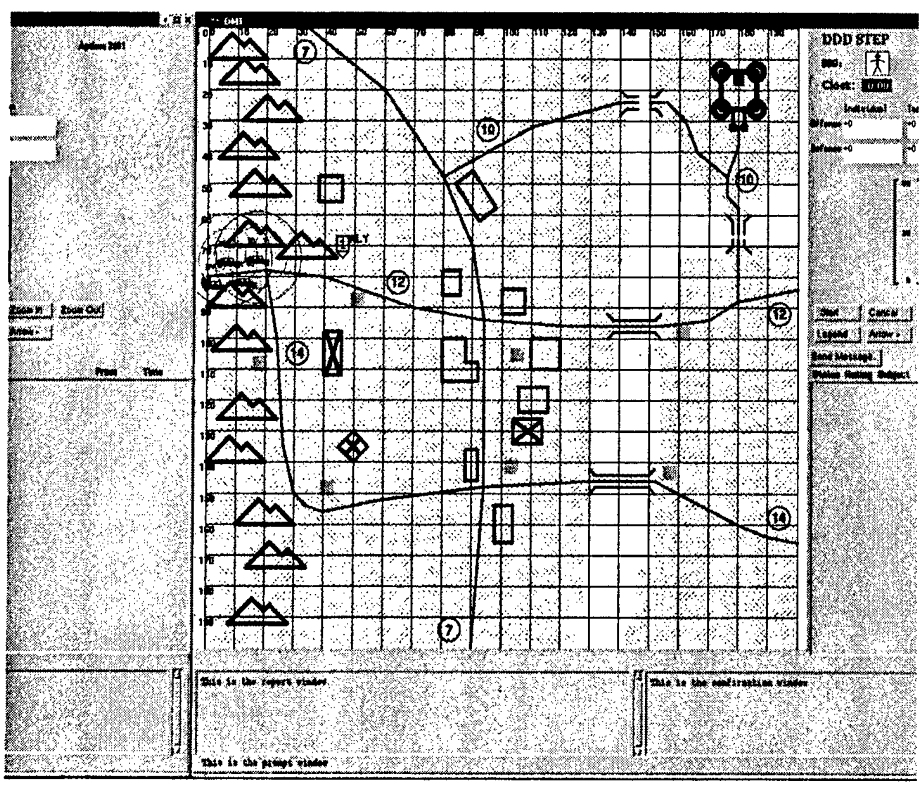

Figure 3. A MOUT scenario in the DDD for studying future job requirements.

For example, Figure 3 shows a screenshot of the DDD as it has been developed for a project to provide a test bed for studying the job requirements of the Army After Next. Because of the anticipated digitization of the battlefield, the knowledge, skills, and abilities of tomorrow's NCOs will include an increased emphasis on digital skills and on the adaptability of these skills to new situations and equipment. The DDD-STEP, the simulator developed for the project called STEP, simulates the jobs of the future to allow the collection of the criterion measures and validation. Some of the simulation capabilities developed for the STEP version of the DDD have been applied in the current version of the DDD-MOUT. For example, we reused features that support tasking teams with identifying non-combatants, and we reused the layout of a small urban environment in the STEP project.

In sum, the DDD synthetic task environment offers a number of capabilities to develop hypotheses about future decision skills, test them, and provide training development opportunities. These capabilities are:

- *Veridicality of domain representation*: The DDD interface provides functional fidelity for many complex decision making tasks (from AWACS airborne command and control through MOUT operations) for both individuals and teams. When it is carefully configured, the DDD can elicit performance that is predictive of performance on real-world decision tasks.
- *Economy of use*: The DDD can be configured rapidly to represent a range of mission types (e.g., assault, defense, and peacekeeping) at a range of mission scales (from infantry unit to joint forces).
- *Measurement*: The DDD is instrumented to measure behaviors and interactions that are meaningful to operational users (such as students) and to scientists who conduct and publish basic and applied research.
- *Models of intelligent resources*: The DDD supports intelligent agents that can stand in for teammates, and serve as tutors and decision aids.
- *Speech recognition and generation:* In a training application for the Air Force, intelligent tutors in the DDD interact with students verbally by interpreting and generating voice communications.
- *Community of users*: The DDD is used in more than 25 military, government, academic, and commercial laboratories, and its users have produced more than 35 journal articles, book chapters, and conference presentations concerning DDD studies.

Results

The current research effort produced two types of results. First, as Figure 1 shows, we analyzed interview data to identify specific instances of future-technology impact on MOUT leadership decision-making. The interview-data results were used to develop the simulator requirements, the scenario elements, and an initial scenario script. Second, we developed the prototype DDD-MOUT test bed and exercised it with the two Aptima operational analysts who play a platoon leader and squad leader, respectively. We report these results, below.

Interview Results

We analyzed our interview data to identify the cognitive and decision-making implications of potential technology effects that our experts noted. We uncovered specific examples of the potentially critical and far-reaching effects of future technology on MOUT operations. The next paragraphs contain a discussion of the issues that SMEs raised as well as the cognitive and decision-making implications of those issues.

Expert Comments. MOUT experts identified a concise set of challenges that confront MOUT leaders in conventional and future technology environments (Table 2). These challenges are, in effect, objectives of decision makers: to develop simple plans, to deconflict lines of fire, to compose communications that are quick and clear, etc.

Table 2 *Decision Challenges Noted by Subject Matter Experts (SMEs)*

SME Priority Ranking	Challenge
1	Simple flexible plan in which squad leaders know their roles
2	Deconflict lines of fire. No fratricide
2	Communicate complex info quickly & clearly
2	Coordinate movements and fires
3	Be aware of complex spatial array of threats, incl. above and below
3	Consider complex building layouts in plans
3	Understand the geometry of your actions
4	Employ all of your available assets
5	Don't telegraph intentions to the enemy
5	Take non-combatant rules of engagement into consideration

These challenges, when crossed against the four levels of technology, formed the matrix with which we elicited expert insights into technology benefits and pitfalls. That matrix had the form illustrated in Table 3.

In discussing these challenges with respect to specific technologies, decision makers identified almost two dozen "tradeoffs," in which technology brought new potential to decision making, but did so at a cost. These items populated the cells of our matrix. The full list of tradeoffs is presented in Appendix A.

Broadly stated, we gleaned from our experts that to use the future technologies well, leaders of small units will need strong skills in information management, spatial reasoning, critical thinking concerning information and inferences, and teamwork (specifically communication and coordination). For example, a 2-D map that provides a platoon leader with much more data about enemy positions affords him an opportunity to plan attack and escape routes, rather than improvise these from instantaneous, incomplete verbal spot-reports. However, to use this future technology to plan, the platoon leader will need (a) information management skills to filter large volumes of information, (b) advanced spatial reasoning skills to make facile use of the platoon

Table 3 *Form of the Matrix Created by Crossing Challenges and Types of Technologies*

Challenge	Information Acquisition	Information Analysis	Decision Selection	Action Implementation
Simple flexible plan				
Deconflict lines of fire				
Communicate info quickly & clearly				
Coordinate movements and fires				
Be aware of complex spatial array	Technology benefits and pitfalls			
Consider complex building layouts				
Understand the geometry of actions				
Employ all of your available assets				
Don't telegraph intentions				
Consider non-combatant rules of engagement				

leader's map-views of the battle, and integrate that understanding with the 3-D, tip-of-the-spear views of the battle from the video feed of the squad leader, and (c) critical thinking skills to critique his or her assessments and plans. Beyond this, (d) new communication and coordination skills may be required to enable the platoon and squad leaders to build a shared representation from their dissimilar displays.

Information management problems are likely to have a cascading effect on other cognitive tasks, such as spatial reasoning or planning. As Entin, Serfaty, and Kerrigan (1998) have shown, high workload causes difficulties in recognizing critical information and in filtering out non-critical information. Thus, high workloads associated with information management generally could cause problems performing any one cognitive task, such as spatial reasoning. The reverse may also occur: spatial reasoning challenges may hinder information management. Moreover, errors in filtering and processing can lead to unnecessary information push and pull in communications. Worse, an overtaxed squad or platoon leader might decide not to pass on information that would have been valuable to the rest of the team.

Spatial reasoning skills may be particularly important to leaders of OFW at the platoon and squad levels. Our experts noted that leaders often have difficulty recognizing all the lines of sight in an urban environment, and that it is taxing to allocate resources to cover these areas or simply find the safest route through them. In addition, experts noted that technologies that could help leaders handle these challenges carry costs. Spatial displays themselves can elicit a kind of under- or over-reliance from users that would impact teamwork and coordination. The OFW capability for automated sensing will allow enemy locations to be presented against a background of the local environment or territory, including building floor plans, transportation routes, etc. The potential positive benefits of this technology should be obvious, in promoting increased levels of situation awareness.

On the other hand, there are potential negative benefits as well. For example, Soldiers using this type of technology will be required to face more severe 4-D (three spatial, one temporal) reasoning demands than in unaided operations. One important potential problem known to be associated with these increased spatial reasoning demands is what has been called "attentional narrowing." Empirical studies indicate that when an operator is provided advanced forms of automated mapping technology, a narrowing of attention (paying attention to the displayed map, and over-devoting cognitive resources toward spatial processing of the displayed information) at the expense of attending to other, yet not displayed sources of information, can occur (Olmos, Wickens, & Chudy, 2000; Horrey & Wickens, 2001). This can result in a substantial loss of situation awareness over elements of a scenario that are not included in the map depiction.

A second problem is what we will call "inference overload"; the more inputs a leader has about the locations of threats—from heat signatures or from acoustic equipment that senses fire directions—the more spatial relationships he or she has to map. Route-planning, especially dynamic replanning, becomes more difficult in this case. A third problem concerns the need to communicate displayed information. While squad leaders will use their own eyes and sensors to mentally build up a picture of threat locations in elevation or 3-D, the platoon leader may use 2-D digital maps in plan view to plot threats and routes. When displays differ between the squad and platoon leader, the two may have to integrate this spatial information through verbal communications. We have witnessed this phenomenon in a major Future Joint Forces exercise (Freeman, et al., 2002); it imposes a significant communications load on leaders[1].

In sum, OFW technology may change the cognitive challenges of MOUT leadership. This is an important finding, not the least because decision-making errors at the platoon and squad levels can have catastrophic effects. Fortunately, training can be developed to teach leaders techniques for using the technology well. Our data hinted at training objectives, and the research literature hints at methods. For example, leaders may benefit from training in critical thinking concerning the recommendations of decision support systems. Cohen, Freeman, and Thompson (1998) validated a method of training critical thinking that (a) sensitizes decision makers to opportunities to critique assessments and plans and (b) focuses their attention on gaps in knowledge, invalid assumptions, and conflicting interpretations of the evidence. This technique might be useful in training OFW decision makers to rely on OFW decision support when it is appropriate to do so, refine it when opportunity allows, and reject it when necessary. Similarly, OFW leaders might benefit from techniques that train rapid assessment of spatial relationships. These range from simple rules of thumb for handling 3-D spatial problems in two dimensions, to more complex solution techniques. For example, submarine experts often break down the highly complex and uncertain geometries of navigation and tracking into manageable sub-tasks with simple rules (Littleton, Schunn, & Kirschenbaum, 2001).

Results of Simulator Development

Our current simulated MOUT environment tests the ability of a platoon and squad leader to move their forces between buildings in one sector of an urban site in order to clear enemy combatants. The scenario terrain is inspired by the geometries of the Army's McKenna MOUT site at Fort Benning, Georgia. Combatants fire on friendly forces in the street from building windows, towers, and alleyways

[1] If leaders each possess several displays (some in 2-D, some in 3-D), they will each face the significant problem of integrating information from those displays.

between buildings; they also emerge from the sewer system. Much enemy activity is inside buildings where they can shoot from covered positions at friendly forces entering the buildings to clear them. Figure 4 depicts the initial state of the scenario, in which players have not yet detected enemy forces inside the buildings. Although presented in black-and-white for the purposes of publishing this report, color was used in the simulation screens.

Enemy forces become visible if the player moves an asset (e.g., a squad member) close to a target wall and "enables" simulated heat-sensing technology to show individuals on the other side. In the screen shot in Figure 5, a player has enabled this technology, represented by concentric rings around icons representing his squad members standing outside the building. The outside black ring has detected one human each inside two different rooms. Friendly forces are equipped with Global Position System (GPS) devices so that the leaders know where they are. Players communicate verbally what activities are occurring inside a building (e.g., "You've got two enemies in north-eastern part of floor three. Move northeast to the entryway.")

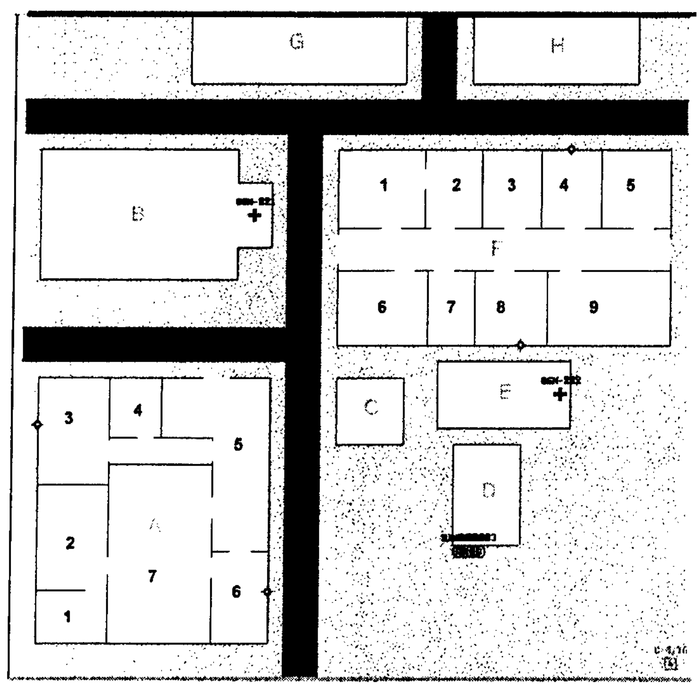

Figure 4. Beginning state of DDD-MOUT scenario.

In addition, snipers appear in a mosque tower and on the top of another building, while two enemies emerge from manholes in the middle of main street (one of six possible manhole exits), thus simulating some of the dimensionality of the MOUT environment.

In response to these threats, players can instruct friendly forces to use the various weapons, including a simulation of a shape charge that breaches building walls.

<u>Script</u>. The players receive information resembling a briefing about the simulated operation and its array of combatants and non-combatants. Over the course of the scenario, the players discover two buildings—A and F in Figure 4—are occupied by mixed groups of enemies and non-combatants. These do not appear until the players move a squad member within one of its

first range rings, and they are unidentified, leaving the player uncertain about how to engage it, until the squad member moves even closer. Two enemies appear in the hallways of Building F. There is one sniper on top of Building E and one on Building B. If an asset is moved too close or within range of either sniper, as with the enemies inside the buildings, it is killed.

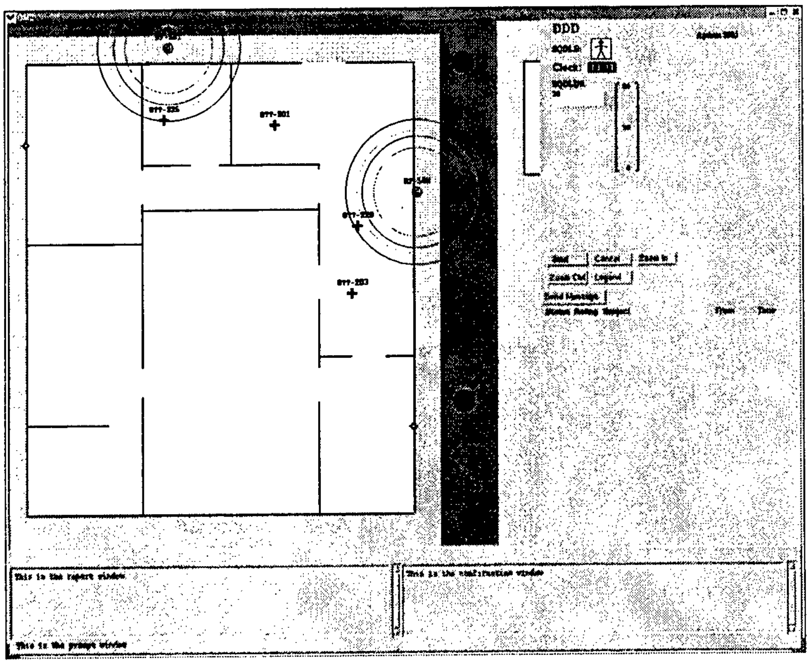

Figure 5. DDD-MOUT threat-sensing view.

Players are briefed with the following information:

> You are the Second Platoon Leader assigned to Charlie Company 4/16 Infantry Battalion. Your unit has been engaged with an occupying force in the country of Atlantis for several weeks. Decisive weapons and overwhelming forces have forced the enemy to abandon established defensive positions and flee into cities and the surrounding mountains. Charlie Company is transitioning from fighting in the open with tanks and artillery to fighting in rugged mountainous terrain and within cities.
>
> Your unit is now on the outskirts of the town of Irbil that has two very important buildings that could be used as enemy strongholds – the city police station and the headquarters of the occupying forces political party. Both buildings were stocked with an assortment of weapons and ammunition prior to hostilities and local informants indicate that there has been a lot of movement inside both buildings. You have been ordered to clear both buildings and secure any enemy personnel and weapons.
>
> The buildings are located approximately one block from each other and there is a mosque located between them. The mosque includes a tower approximately 60 meters high that would provide direct line of fire to the fronts of both buildings. There is an extensive sewer system in the city with many drains and manholes in the streets.
>
> You have decided to use 1st squad's squad leader and his bravo fire team. The fire team consists of four Soldiers; three equipped with M16s and one with a M249. Each Soldier is carrying two fragmentation grenades, two "flash bang" grenades, and one shape charge capable of breaching most building walls. Each Soldier wears a GPS device giving you

the capability of knowing there locations at all times. Soldiers also have an infrared capability that allows them to see heat signatures through most walls.

Intelligence Update

A group of individuals dressed in civilian clothes was seen entering the sewer system through a manhole located in the northwest section of town approximately 30 minutes ago. Unmanned aerial vehicle video shows that there are two snipers in the vicinity of the two occupied building. One is located in the mosque tower (building B) and the other is located on top of building E. The sniper's fields of view cover the entrance to buildings A and F.

Mission

Both snipers need to be eliminated immediately. Once the snipers pose no threat, clear the buildings. You can decide which building to clear first, or you can split your team and clear both buildings simultaneously. Do not enter the sewer system but remain aware of the various potential exits from the system.

Results of Exercise Run

The DDD-MOUT scenario was played by a two-member team to explore how well certain decision challenges suggested by the SMEs were implemented in the DDD and to gain some insights concerning the pitfalls of potential OFW technology. One player acted as platoon leader. He advised the squad leader concerning threats and ordered some movements. The player acting as squad leader engaged targets.

The exercise ran about 28 minutes, in which, even given an unrealistically slow game-tempo (a default setting), the player controlling squad members lost two men out of a four-man squad and eliminated only half of the hostiles. The ability to sense individuals on the other side of a wall led to simple tactics and planning. However, the number of enemies to identify and eliminate was large, and this required leaders to carefully place squad-members and fire accurately, lest they be targeted by hostiles.

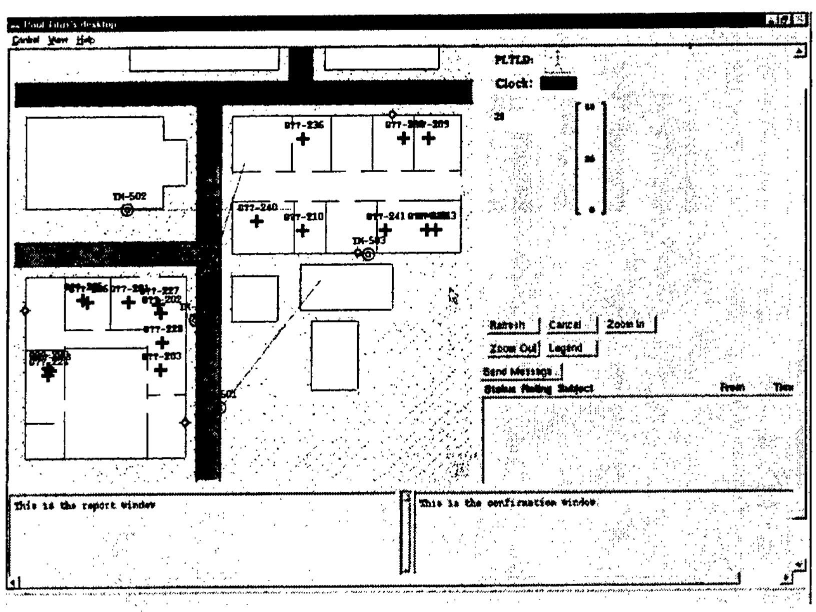

Figure 6. Team ready to attack.

Early in the scenario (see Figure 6), the team of two players commented that their plan was simple, a clear sign that the scenario itself was simple. First, they eliminated the snipers as they were told to do. They then investigated how the buildings were occupied by walking around them with the heat-sensing technology turned on. They planned to select an entry to the buildings after completing this circuit. In the screenshots, the circles (blue in the actual simulations) are squad members while the black crosses are enemies or civilians, each with an identification code. This code is either question marks ("???") indicating the individual has not been identified by a squad member, a "GNH" meaning Ground-Non-Hostile or non-combatant, or a "GHR" meaning Ground-Hostile-Rifle or an armed hostile. The straight thin lines projecting from the squad-member circles (red in the simulation screens) are the paths that the player has given the synthetic squad members to follow. In this case, the Squad leader has directed two synthetic squad members to enter the building from the street entrance and two others to enter by breaching the southern wall of the building. There are points on each building, denoted by a tiny black circle on the perimeter, that show where a breach is feasible. All the squad leader needed to do was instruct the synthetic squad to blow up that part of the wall and enter. However, both occupied buildings turned out to be heavily populated, so the players decided to mass power at the entrances and outside doorways, and take one building at a time.

Though the game tempo was slow and the enemies were scripted, the team was surprised by a hostile that appeared in a hallway as they were preparing to clear a room. Figure 7 shows this moment and the unexpected hostile annotated in this screenshot with a circle around its "+" symbol. There are different ways to interpret the player's surprise at this discovery. On the one hand, we could attribute this to workload. The four-man squad was vastly out-numbered and unable to process each entity quickly enough after detecting them. We speculate that two or three squads and squad leaders would have had better success with the technology in this scenario. On the other hand, we could be seeing a negative side effect in players' over-confidence in the threat-sensing technology. That is, the player using the range-rings feature may have trusted that merely wandering around the area (in an unsystematic fashion) would reveal all the threats. However, the simulated technology was quite limited in range, which required that the squad systematically sweep the areas in all directions. The squad that missed a corner missed an entity. This is precisely the phenomenon that MOUT trainers at ARI have observed in simulated MOUT exercises.

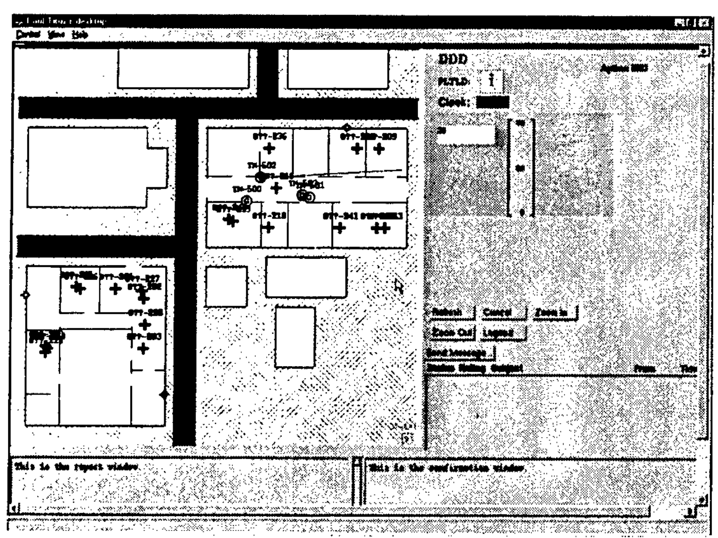

Figure 7. Unexpected hostile.

Some predicted effect of the technology bore out—specifically, having threat-location data simplified the planning and tactics, enabled the team to focus on the enemy, and lessened the frequency with which the team operated reactively and defensively to unexpected threats. The threat-sensing technology enabled the leaders to support one another in pushing and pulling information about threats.

For example, the snipers in towers and in the sewers did not pose significant problems. At least, the team did not seem to treat these entities differently than others appearing in the rooms of buildings, nor did the team's progress seem to slow down when these entities appeared. A hostile appearing suddenly out of a manhole and advancing towards the occupied buildings did not present the surprise or additional workload that we expected. However, a hostile appearing in a hallway—a hostile that the team had simply missed—disrupted operations significantly. This suggests that teams must be taught specific tactics, techniques, and procedures for using new technology effectively, and that they must temper their reliance on the technology with an awareness that it provides a limited, selective map of the battlespace.

Discussion

The Objective Force Warrior (OFW) concept aims to leverage the many recent advances in information technology and automation to augment the capabilities of the future Soldier. The potential effects are reported with a distinctly positive flavor. In the human factors and cognitive engineering communities, however, it has become almost axiomatic that the introduction of automation is a double-edged sword. Along with nearly every documented case of effective automation use come inevitable cases of automation misuse, disuse, and abuse (Parasuraman & Riley, 1997).

As we see it, there are three keys to achieving the maximally effective use of automation in OFW. These are to:

- **Identify the spectrum of potential decision-making challenges** that will arise out of increasingly complex human-automation interaction (HAI) regimes, and **validate these challenges.**
- **Identify training objectives** that address these increased challenges and **empirically validate training** that addresses these objectives.
- **Develop methods and technologies** for identifying decision requirements and conducting empirical validations of these requirements and training to address them.

Our work resulted in an initial test bed that allows the Army to go beyond interviewing SMEs about the future battlespace, and beyond computational modeling of experts in an imagined battle. This test bed enables researchers to observe and study human players as they filter information, communicate, and coordinate using simulations of technologies that do not yet exist. It allowed us to gather data on human operators' tactical decisions as they shared information and planned an attack in a simulated urban environment with envisioned, threat-sensing technology.

The results of the pilot simulation study suggest that there will be both positive effects of the technology, as well as unintended negative effects. Specifically, we noted that even in an ideal world—with reliable communications and a scripted enemy—the threat-sensing technology simplified and focused the operation, but may have lulled the players into a false sense of confidence in the abilities of the technology.

Future research should expand this capability into a rapidly reconfigurable tool that can simulate a wide range of MOUT challenges and potential technologies. For example, we know from our research earlier in this effort that there may be consequences for the squad and platoon leaders attempting to process spatial layouts involving many threat locations. The number and complexity of fields of fire can be difficult to consider.

The DDD scenario lacks important MOUT challenges such as the potential for fratricide (the DDD currently does not allow friendly forces to kill each other), intelligent enemy forces (the DDD currently employs scripted enemy forces and simple branching between scripts; more sophisticated enemy responses may be needed), and an enemy who employs unfamiliar rules of engagement (the DDD does not, for example, support enemy use of human shields, a necessity in some urban combat). However, these features can be implemented within the DDD. Doing so will help expand the tool from a validation test bed, into a rich environment for *discovering* new MOUT challenges, validating those, and developing training to address new challenges.

The innovation we aim for in future research and development is to create a lightweight, rapidly reconfigurable simulation environment that will house a full research program for exploring the decision requirements imposed by new technologies, validating them, and testing the training that delivers new decision skills to Objective Force Warriors.

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Appendix A: MOUT Challenges by Technology Level

Note: The following challenges to OFW decision makers are organized into four levels of technology proposed by Parasuraman, Sheridan, and Wickens, 2000. Some challenges may pertain to more than one level, typically higher levels that incorporate the features – and thus the faults – of lower ones.

Information Acquisition – A map-based display indicates the locations of own forces, enemy forces, and non-combatants

- Platoon leaders may become reliant on the technology, but it may not always work.
- The area of view of the sensors is limited. The leader needs to realize that the enemy will intentionally move out of view of the sensors.
- If system is less than perfectly accurate, the leader will need combine information from the system with other information, such as knowledge of enemy tactics, techniques, and procedures. The leader must know how to weight all of this information.
- The leader must be able to read and understand floor plans.
- The leader must understand when the squad does not understand his location instructions. This is always a problem, but it may increase or decrease as communications change with the new technology.
- If there are many threats, the leader will have a difficult job of filtering information. The leader must be good at focusing attention, using filters, knowing the state of filters (e.g., I've filtered out enemy to the east, but they're still there and coming my way).
- The leader needs spatial reasoning skill to understand spatial relationship of enemy troops to own troops. These relations define fields of fire, safe harbor and safe passage areas, etc. The leader must be able to construct the space in your mind.

Information Analysis – The display locates zones of threat and safety (plus features above)

- The leader may know the interior structure of the building, but the layout of rooms is more dynamic than she expects. An explosion introduces a new doorway, e.g., from an area you have cleared to one you have not. The leader must be able to infer that the room has changed if the enemy disappears when there was previously no way out. Similarly, fields of fire may change very dynamically as interior structures change.
- Changing the interior structure of a building can be dangerous. Walls may contain electrical or plumbing or gas lines. There may be heavy equipment or enemies on the other side. Leaders must learn rules of thumb, such as "Don't try to enter under a window because the sink or bureau may be there." Leaders must understand local building standards and cultural habits of placing furniture.
- The technology may not clearly indicate how floors are layered, particularly in structures with split-levels and interstitial spaces.
- The leader needs to know to look for 3-D threats that are not obvious, e.g., a sewer system, an attic, interstitial spaces, and crawl spaces. The enemy may drop a floor on you. This is a threat that the system may not take into account. You need to know what threats the system does "understand."

- Floor plans can be wrong. Because of incorrect floor plans, a squad member can go charging into a closet thinking it is a major room; a leader may push a whole team into a 2x2 toilet with their gun safeties off. Leaders need to judge the accuracy of floor plans as squads conduct surveillance or move through buildings.
- As enemy firing patterns change, the leader may overestimate (or underestimate) misjudge enemy movements (e.g., they're moving to the East) or the number of enemy. Leaders need to estimate the enemy well and predict their movement based on shifts in firing patterns.
- Leaders need strong route planning skills to leverage the information the system gives them. It is one thing to know that there are eight enemies on the third floor and one on the second floor. It is another thing to approach both locations safely and without revealing own strength and intentions.

Decision Selection – The system recommends routes to assault the enemy and protect own troops (plus features above).

- Decision aids typically weight decision factors. The leader needs to understand these weights and when to alter them. For example, the system may propose a route based on avoiding mosques and churches, but if that is where the bad guys are, these parameters must be adjusted.
- The rate of information update may not keep up with troop movements. In a scenario in which the enemy moves rapidly (e.g., if enemy uses rapidly bounding overwatch), locational information at a given moment may not be trustworthy. Leaders must understand the refresh rate or currency of information.
- Leaders need to know when to rely on the technology, and when not to do so. E.g., when you are in a firefight, you need to just yell to people, not key in messages.
- The leader must understand the rationale for the system's plans, and its weaknesses in planning. In general, future leaders need to be good at thinking against the machine (critical thinking). This is very tough when you are so tired you cannot remember the last sentence you uttered.

Action Implementation – System issues fragmentary orders (FRAGO) of route plan, immediate objectives, and required weapons and sensors (plus features above).

- The enemy may anticipate the system's plans.
- Decision support systems do not represent important human aspects of battle. The leader must understand what these aspects are and be prepared to compensate for this. If the system sends Soldiers into a room of mutilated children, the leader needs to lead them out and refresh their psyches. If the system assigns exhausted Soldiers to a key mission, the human must override this decision.
- The leader quickly may lose control of the mission if his team becomes stretched out as they respond to a FRAGO. The leader must be sensitive to the system's timing and coordinate his team effectively.
- The leader needs to be very sensitive to the risks of a mission...because the system may not be.