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MAVEN-SA: Model-Based Automated Visualization for Enhanced Situation Awareness

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14. ABSTRACT *(Maximum 200 words)*:

Report developed under a Phase I Small Business Technology Transfer Research (STTR) program contract for topic A04-T002. The research reported here explored methods for training battlefield visualization through human-computer visualization. The objective was to determine whether an adaptive visualization system that strongly leverages current findings in cognitive and perceptual psychology and in situation awareness could be designed that would improve Army schoolhouse training. The research approach had three focal points. First, we reviewed the extant literature on perceptual and cognitive visualization and mixed-initiative interaction as related to military situation awareness and decision making. Second, we developed a company level Military Operations in Urban Terrain (MOUT) scenario to inform our inquiry. Third, we developed a limited capability visualization prototype to test core approach concepts. The work conducted during Phase I lays the foundation for a Phase II plan to develop a usable schoolhouse tool for training battlespace visualization and to test the utility of this tool in an experimental setting.

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MAVEN-SA: MODEL-BASED AUTOMATED VISUALIZATION FOR ENHANCED SITUATION AWARENESS

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Introduction

Identification and Significance of the Problem

As the vision of network-centric warfare (NCW, Alberts, Garstka, and Steins, 1999) becomes reality in the Future Force, it is clear that trading steel for information represents a true revolution in military affairs. One of the main goals of NCW is to eliminate traditional information stovepipes to speed the flow of information to the end user and to rapidly increase the rate at which information is transformed to be militarily significant and decision centered. Irrespective of the concept and goals of NCW, however, sound, rapid, and accurate decision making remains at the heart of all aspects of battle command. To be truly useful for decision making, new information must be integrated into the warfighter's mental image of the current situation and accurately related to the mission. Having a solid understanding of the situation is necessary to ask the right questions; having the right information is necessary to answering the questions correctly and understanding the consequences of the answers.

Developing accurate and sufficient mental models for battlefield situations and decision making is a necessary prerequisite for understanding the situation and acting on key information. Visualizing situations, information, and processes is a useful technique for developing such mental models, understanding how new information relates to decisions, and understanding what information is necessary to make good decisions. This involves at least three different levels of warfighter knowledge that must be learned to achieve and capitalize on information and technological superiority: (a) knowledge of the basic visualization skills that support military decision making, (b) knowledge of basic visualization tools available to military personnel, and (c) knowledge of how to apply visualization skills with the available tools in militarily relevant situations.

We propose to improve the quality of military decision making instruction regarding visualization of information by, (a) further developing the scientific basis for developing mental models, visualizing information and situations, and teaching visualization techniques, (b) by developing courseware to present these concepts in (a), and (c) by developing computer-based instruction software to facilitate the teaching process and reduce training costs. This effort will demonstrate the effectiveness and utility of human-computer visualization for military decision making and represent a significant step forward in digital instruction technique and product.

A technical challenge in this information age transformation is to understand how various technological capabilities can be combined, utilized, and embraced in a manner that will fundamentally improve mission effectiveness. This requires not only an understanding of the technology, but an understanding of how soldiers can best use that technology, and how that usage can fit into or transform military doctrine. At the core of military doctrine is the Military Decision making Process (MDMP), a methodical, deliberate analytic process for problem-solving that pervades all military operations. If transformation is to truly represent a revolution in military affairs, it must enable fundamental improvements to the MDMP and tactical decision making.

One evolutionary change to MDMP is the move towards a running estimate of battlespace information that will allow more rapid assessment, awareness, and understanding of the situation. The goal of this change is to ensure information superiority, enabling more rapid decision making, and result in more decisive battles. For example, the development of the Global Information Grid (GIG, Alberts & Hayes, 2003) will vastly increase the amount of information available to all echelons of command and will allow information sharing and collaboration to be conducted in a peer-to-peer manner. This will enable information to break beyond the bounds of the traditional command hierarchy, in effect, pushing the power of information to the edge of the force network. To the warfighter, this means both the empowerment that more information provides, but also the burden of making sense of that information. Developing the technology that will allow warfighters to rapidly understand and process large amounts of dynamically changing data is critical to realizing the NCW vision of dramatically increased mission effectiveness, self-synchronization, improved information sharing and collaboration, and an improved, shared situation awareness (SA, Alberts, 2002).

Phase I Research

We proposed to combine state of the art techniques in situation awareness, agent-based cognitive systems, information visualization, and intelligent instruction interfaces to create a system for teaching visualization skills to military officers at the company command level. Phase I demonstrated the feasibility of our approach by addressing three main areas of research:

1. Models for SA - We conducted a goal-directed task analysis (GDTA) of the cordon-and-search mission type.
2. Visualization Optimization - We applied novel visualization tools designed for scientific visualization to a Cordon-and-Search scenario.
3. Visualization Training Assessment - Researched training gaps between what is taught in traditional military schoolhouse training and skills needed in current military operations.

These research areas are addressed in the context of developing new training techniques and tools for instruction that is contextually sensitive to the warfighter's needs. From this work we have developed four possible options for future development. We propose to implement planned system by augmenting an existing visualization toolkit, developing a framework for implementing instructional scaffolding, and developing coursework that addresses mental model development, use of visualization techniques, and visualizing complex battlefield relationships. We ground the problem and motivate our research efforts by focusing on the context of Military Operations in Urban Terrain (MOUT). Specifically, we address the information, decision making, visualization and situation awareness needs of an FCS company commander conducting cordon and search missions.

Background

Decision Making Challenges During MOUT

MOUT operations represent one of the most challenging and dangerous of all classes of military missions because terrain, infrastructure, cultural issues, and other aspects of the domain negate many of the technological advantages held by the U.S. military. Information, understanding and use of that understanding to make better and faster tactical decisions is among the most important weapons for achieving success in the urban environment. A frequent type of mission in which company commanders face numerous decisions is cordon and search. In this type of operation, commanders are typically searching for specific items (e.g., weapons) or people (e.g. fugitives). The main tasks for a cordon and search are moving to the objective, establishing the cordon to isolate and secure the objective, and conducting the search. While a cordon and search is conceptually straightforward, there are several key decisions that must be constantly evaluated and many factors that a commander must consider. Some key decisions are:

- What is our task and purpose (mission)? How do we know when our mission has been accomplished?
- Has the tactical situation changed? If so, has it changed the mission?
- Is there an unexpected threat? If so, what is its nature?
- Can I still complete the mission with available resources? If not, are additional resources available?
- Is there a secure evacuation route if necessary?
- Each of these decisions relies on an accurate assessment of available information, an understanding of how that information impacts the current situation, and the commander's ability to use that understanding to accurately predict future situations that result in a successful mission.

In evaluating these decisions, commanders are trained to consider several key factors, each of which evokes its own set of questions. Factors for cordon and search might be:

- **Mission** – What type of search is required, what is to be sought, and what is the desired end-state? Is the mission conducted under surgical, precision, or high-intensity conditions?
- **Enemy** – What type of resistance is to be expected? How well are they armed and organized? Are they likely to be reinforced?
- **Terrain & Weather** – What is the geographic layout? What types of buildings are being searched? What are best routes in and out each building and the area of operations? What are the best covered and concealed locations for friendly or enemy troops?
- **Troops Available** – Do I have enough troops to accomplish the mission? Do they have the right weapons, equipment and training? Do they have enough ammo and supplies?
- **Time Available** – Do we have time to be careful and methodical, or is speed critical?
- **Civil Considerations** – Is the local population hostile, friendly, or neutral? Has there been a history of unrest in the area? Are there mosques, churches, schools, hospitals, or other no-fire areas? What other cultural considerations must be considered? How do the Rules of Engagement impact the mission?

These key decision factors are, of course, interrelated such that changes in one factor can affect other factors. For example, any change to the mission will cause almost all other factors to be reevaluated. Although commanders are responsible for evaluating the key decisions and factors constantly, it is not possible for them to deliberately consider each question constantly. Instead commanders and other expert decision makers focus on changes to the situation to prompt deliberate evaluations; this reduces and simplifies the commanders' decision to just one: has my situation changed? Instead of evaluating each new piece of information according to a vast set of criteria, the one question that can quickly filter irrelevant information is whether the new information changes the current situation. If it does, then the deeper issues can be further explored.

Given enough time, skilled commanders can typically make accurate evaluations of new information relative to the current situation. However, when information is arriving too quickly for proper evaluation, there is an increased likelihood that something will be missed. With a predicted order of magnitude increase in available information and the availability of unprocessed intelligence envisioned by information-age transformation (Alberts & Hayes, 2003), adequately assessing all new information in a timely manner will not be possible without additional fusion and other automated information processing to facilitate warfighter understanding. This problem is further compounded with the proliferation of unmanned and unattended sensors being developed as part of the Future Combat Systems (FCS), especially those organic to the FCS company, because that information will most certainly be unprocessed by higher echelon intelligence staff. Furthermore, much information that is critical for urban operations is cultural or otherwise non-physical in nature. Given the challenges of large volumes of information that can be both uncertain and unprocessed, how can future commanders make use of this new information to better understand their situation and the tactical decisions that must be made?

Situation Awareness to Support Decision Making

Situation awareness forms the foundation for military decision making and task execution. Soldiers must do more than simply perceive the state of their environment. They must understand the integrated meaning of what they perceive in relation to their goals. SA, as such, incorporates the soldiers' understanding of the situation as a whole and forms a basis for decision making. How they identify their options for action is a function of their situation awareness – the understanding of what has happened and of the resulting battlefield situation. Their SA provides the context in which the decision takes place. Battlefield visualization displays must therefore provide warfighters with adequate context to allow them to gain and maintain the SA they need to make effective decisions. In the demanding combat environment, superior SA can bring tremendous advantages by promoting information dominance, improving security and survivability, and optimizing lethality.

Situation Awareness is formally defined as "*the perception of the elements in the environment, the comprehension of their meaning and the projection of their status in the near future*" (Endsley, 1988). Situation awareness therefore involves perceiving critical factors in the environment (Level 1 SA); understanding what those factors mean, particularly when integrated together in relation to the warfighter's goals (Level 2 SA); and at the highest level, an understanding of what the situation will be in the near future (Level 3 SA). These two higher levels of SA allow warfighters to function in a timely and effective manner.

Similarly, the Army has operationally defined situational awareness as "the degree to which one is able to maintain a common operating picture of all aspects of the tactical situation" (Department of the Army, 2002a). This definition corresponds closely to Endsley's Level 2 SA and at the company level is measured by answers to the following questions:

- Where am I (relative to where I'm supposed to be)?
- Where my soldiers and what are is their status?
- Where are the friendly forces and what is their status?
- Where are the enemy and what is its capabilities?

One experimental technique for reacquiring SA during a mission is for the company commander to issue the "Go Firm command". This command requires subordinate units to pause current operations, assume a hasty defensive posture and provide situation reports to the commander. With advances in blue-force tracking technology, much of this information may eventually be provided automatically, however, the commander still needs to process that information and understand how it affects his[1] assessment of the situation. The further challenge is how to present this information in a way that does not unduly increase the commander's cognitive workload and doesn't limit the degree to which the commander can sense other information in the immediate environment. Graphical and other low-workload means for presenting information to the commander are essential for enhancing the commander's ability to achieve and maintain high levels of SA. Given that most battlefield visualizations are map-based, graphical information presentation tools must integrate seamlessly within that view.

Visualization Skills Training to Support Decision Making

Battlefield visualization is defined as "the mental process which supports the commander's decision making process" (Department of the Army, 1995). It "lies at the center of battle command" and is "an essential leadership attribute of the commander" that is "critical for accomplishing missions." Battlefield visualization is a three-step command process whereby the commander develops a clear understanding of the current situation, envisions a desired end state, and visualizes the sequences of activity that will move his force from its current situation to the desired end state (Department of the Army, 2002b). Thus battlefield visualization is an inherently human activity that corresponds directly to Level 3 SA and informs tactical decision making.

If a new training approach is to be developed to improve tactical decision making, it must address battlefield visualization and, more specifically, situation awareness. This approach requires a focus on basic visualization skills including identification of information needs and sources; integration of these sources in external visual representations, such as maps and tables; the drawing of valid inferences from these representations; and the integration of new

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[1] According to current military doctrine, all members of the U.S. Army Infantry are male, and hence they are referred to using only masculine pronouns.

information into existing knowledge schemas. This approach will need to draw on flexibility of contemporary digital displays, the personalized instruction of advanced computer-based training systems, and current advances in situation awareness and cognitive psychology research.

Phase I Technical Objectives and Approach

The primary goal of this project is to explore how to use educational technology to support battlefield visualization training. Our goal was to identify opportunities to introduce the concept of battlefield visualization training in to the military schoolhouse and to improve battlefield visualization through the use of innovative computer based training. The result of this improved training should fundamentally improve the battlefield commanders' ability to acquire SA and make decisions. We addressed this training goal in the context of FCS company-level urban operations. To narrow the scope of this effort we will focus on *cordon and search* operations, a high-frequency mission type where timely information, accurate situation awareness, and rapid decision making are especially critical to success.

The challenges for accomplishing this goal were divided into three core areas. These areas corresponded to the main responsibilities and core competences of each MAVEN-SA team member:

1. Understanding the warfighter's needs and the context of tactical decision making (SA Technologies).
2. Develop approach for battlefield visualization training including identifying basic visualization skills, training methodology, types of materials, and core concepts for intelligent computer-based training. (Soar Technology).
3. Creating innovative information visualization and mixed-initiative interaction techniques that support that battlefield visualization. (NCSU).

The project focused on answering several feasibility questions, including:

1. Can specific current skill gaps between battlefield visualization schoolhouse training and visualization skills required by current military operations be identified?
2. Can basic, trainable, visualization skills be identified that fill these gaps?
3. Can an educational technology approach, including specific training modules and software systems, be developed that would produce measurable improvements in these gap areas?
4. Would such an approach actually improve warfighter performance?

The following sections describe the initial vision for how the proposed training methodology and materials might be applied, the context of how they might be incorporated with other decision and performance aids, and their technical and scientific basis.

The Vision: Enabling Tactical Battlefield Commanders Through Improved Visualization Skills

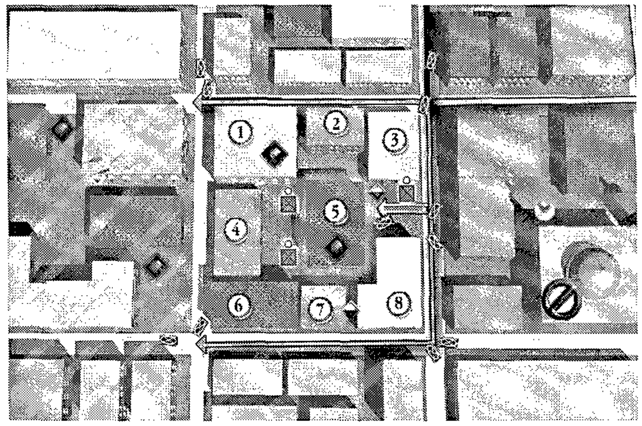

Figure 1. Dynamic information overlaid on urban map reflects ingress and evacuation routes, friendly and enemy forces, friendly and hostile neighborhoods, no-fire areas, and other mission specific information.

As discussed earlier, the key risk of urban operations is that the urban environment can obscure intelligence about the enemy, their strength, and intent until it is too late. The goal is to provide training that will improve the battle commander's ability to visualize the current situation based on the information he has and visualize the meaning of this information so he can fully comprehend its implications and visualize the future status of the operation environment so he can maintain control of the tactical situation. Generally, the creation of these visualizations can be facilitated by the processes of pattern matching or the use of multi-dimensional visual overlays. Examples of pattern matching include visualizing the patterns of obstacles or explosive devices that might indicate high-value buildings or other targets, or might, instead, indicate an effort to canalize friendly forces into a kill zone. Other visualization patterns include cell phone traffic, reconnaissance elements, or civilian activity that might indicate an ambush or attack. More obvious patterns might include red-force tracking that could indicate direction and strength of an attack. While technology exists for visualizing patterns within a single, homogeneous data type, the challenge remains for finding and presenting data and then training leaders to see patterns across data types (e.g., the combination of explosive devices and cell phone traffic).

Visualizing multiple dimensions of the urban environment is another important aspect of achieving and maintaining high levels of situation awareness. How can we visualize avenues of approach, dynamically calculated evacuation routes, subterranean infrastructure, uncertainty and reliability of information, cultural aspects of the area, and the myriad other details that commanders today must try to keep in their heads? Combining structural, mission, intelligence, and cultural information can be overwhelming; training commanders to understand the critical elements of each domain and to leverage visual representations to better convey the situation are additional challenges we needed to address.

Phase I Activities and Accomplishments

Under Phase I of this Small Business Technology Transfer Research contract, we researched the use of educational technology to support battlefield visualization training. Our goal was to identify opportunities to introduce the concept of battlefield visualization training in to the military schoolhouse and to improve battlefield visualization through the use of innovative computer based training. Specifically, we wanted to develop a training capability that would provide significant improvement to a commanders' ability to use visual representations and displays to assemble and integrate heterogeneous information sources to maintain situation awareness, improve planning and aid communication.

During the initial phase of this project we progressed in several areas. Major accomplishments of Phase I included:

- A working scenario was defined on which to determine project feasibility. This scenario centered on a company level MOUT cordon and search mission.
- A comprehensive GDTA was performed to identify the information required by a company commander to maintain SA during a MOUT Cordon and search mission.
- Reviewed appropriate literatures describing:
  - Military battlespace visualization
  - Cognitive and perceptual psychology and linguistics as they relate to visualization, visual languages, and external knowledge representations
  - Computer science as it relates to visualization, visual languages, and mixed-initiative interaction.
  - Education, cognitive and social psychology, and computer science as they relate to general approaches to educational technology.
- Developed a basic visualization capability for perceptual display optimization for MOUT environments, transitioning our STTR academic partners previous work in perception optimized visualization and mixed-interaction interfaces. This display and interaction capability will provide the basis for our intelligent part-task visualization trainer.
- Developed concrete phase II training goals and training tool/environment approaches.

MOUT Scenario: Company Level Cordon & Search

As previously noted, MOUT operations represent one of the most challenging and dangerous of all classes of military missions. Information, understanding and use of that understanding to make better and faster tactical decisions are among the most important weapons for achieving success in the urban environment. A frequent mission type in which company commanders face numerous decisions is cordon and search. During Phase I, we developed a detailed description and analysis of a cordon and search scenario.

Situation: You are the Commander of A Company, 1st Battalion, 30th Infantry. You are part of TF Saber, a brigade task force deployed to Taronia to assist the government and provide security and stability operations until host nation forces are able to secure the region from insurgent forces.

Enemy Forces: Insurgent activity in the Taronian capital of Brovburg has escalated over the last two weeks. The Brigade Intelligence Estimate points to evidence that insurgents have a larger than expected amount of explosives and weapons and are planning more aggressive attacks in order to destabilize the Taronian government. Recent insurgent activity has included 2-3 man rocket propelled grenade (RPG) teams attacks, isolated car bombs and hit and run mortar attacks on coalition and host nation forces. The town of McKenna, the largest suburb of Brovburg, is suspected of harboring a growing cell of insurgents with multiple caches of weapons and explosives. Insurgents in McKenna are often reinforced from the surrounding villages of Luton and Carona, west and east of McKenna. Activity in McKenna has been excessively violent over the last 72 hours. Insurgents have launched multiple attacks, both day and night, against U.S. forces and against Taronian militia attempting to restore order. These insurgent forces are capable of squad size attacks and typically employ ambushes, sniper attacks, RPG teams and Improvised Explosive Devices (IEDs) to disrupt security operations. Insurgents are likely to attack isolated elements and convoys, and then break contact to prevent an all out engagement. The insurgents then dissipate back into the general population and are not easily identified.

Friendly Forces: Higher Headquarters: 1st Battalion, 30th Infantry: NLT 17 1200 March, 1st Battalion, 30th Infantry conducts cordon and search and secures McKenna in order to allow Taronian forces to restore regional stability. NLT 17 1200 March, A Company, the battalion main effort, conducts a cordon and search and secures McKenna in order to allow Taronian forces to restore regional stability. NLT 17 1200 March, B Company secures Luton to prevent insurgents from disrupting A Company's cordon and search. NLT 17 1200 March, C Company secures Carona in order to prevent insurgents from disrupting A Company's cordon and search. NLT 17 1200 March, D Company secures roadblocks on Highway 16 and 31 in order to prevent insurgents from disrupting A Company's cordon and search.

Battalion Commander's Intent: The Battalion Commander's intent is to isolate the suburb of McKenna from Brovburg and the surrounding villages. Once isolated, McKenna is searched thoroughly and insurgent forces brought under control. Weapon caches are located, confiscated or destroyed and suspected insurgents are arrested without creating a hostile environment leading to direct firefights. At the end of the operation, McKenna is secure and clear of insurgents and their weapons.

Mission: NLT 17 1200 March, A Company conducts a cordon and search and secures McKenna in order to allow Taronian forces to restore regional stability.

Scheme of Maneuver: Area of Operations (AO) McKenna, as shown in Figure 3, is divided up into three different zones: Block Zebra, Block X-ray and Block Yankee. One platoon, the security element, will establish checkpoints and cordon off the town. Taronian militia forces will assist the security element in augmenting checkpoint operations. One platoon, the search element will conduct the actual building-to-building search, by block area. One platoon, the reserve element, will stand by to execute on order tasks to assist either the security or search element in their tasks or to conduct other tasks as designated by the company commander. The company HQ element will move with the search element.

Figure 2. Cordon and search tactical situation.

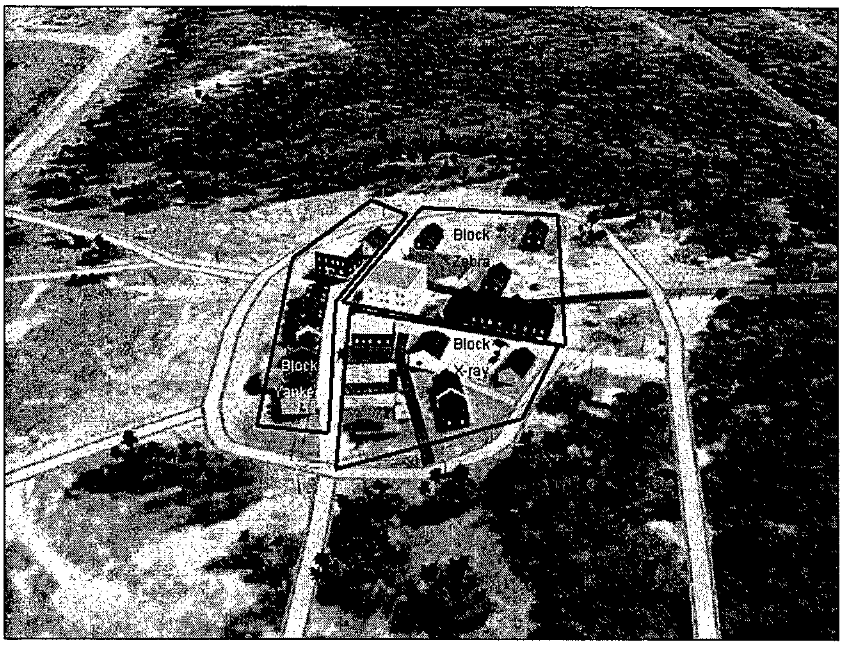

Figure 3. McKenna map with block boundaries.

This scenario implies the following mission considerations for a company commander:

1. Watch out for snipers. When coalition forces are in the vicinity of weapons caches, insurgents have been known to use snipers to divert attention.
2. Insurgents are excellent at "playing along" and appearing friendly to coalition forces in order to prevent detection. Keep your guard up.
3. Vehicle traffic in Block Zebra can be heavy around festival time. Insurgents have taken advantage of this traffic pattern to execute car bombs with both friendly and civilian casualties.
4. Ingress and egress routes are critical to prevent platoons or squads from being cut off and isolated to insurgent attacks.
5. Angry crowds have quickly formed on previous cordon and search operations. Have a plan for crowd control in case things get out of hand.

Subsequent sections address in more detail two of the five mission considerations.

MOUT visualization for sniper threat. When planning to conduct a cordon and search operation in an urban environment, the likelihood of snipers or small 2-3 man enemy teams engaging the cordon and search force is high in a hostile neighborhood. Insurgents may attempt to disrupt, delay or prevent a successful operation, especially if there are weapons or contraband caches that are likely to be found and lost to friendly forces. Commanders must determine the impact of this threat and take measures to actively prevent sniper attacks from occurring.
In planning such an operation, the commander needs to be able to visualize the battlefield. Looking at the results of the GDTA conducted for a cordon and search operation, we will show how improving the commander's visualization would support the information requirements needed for meeting the commander's cordon and search goals.

The GDTA goal 'Avoid Danger Areas' addresses several areas where the commander needs to visualize enemy activity in the AO. Visualizing the location of neighborhoods or residences hostile to friendly forces allows him to better predict where contact might occur. Visualizing likely sniper positions and the fields of fires and observations from rooftops, doorways and windows allow the commander to view potential areas to cover with counter sniper teams or to orient covering fires toward various vantage points that a sniper might occupy.

A thorough assessment of the following is critical to mission success:

- Types of buildings in and adjacent to the AO
- Types and locations of building rooftops, windows and doorways
- Fields of Fire from rooftops, windows and doorways
- Observation from rooftops, windows and doorways
- Routes of ingress and egress to the objective area for friendly forces
- Most likely escape routes for small enemy elements out of the objective area
- Locations of security, search and reserve elements
- Likely enemy sniper positions
- Attitude of civilians in the objective neighborhood
- Evidence of past sniper activity
- Exposed areas where friendly forces are vulnerable
- Cover and/or concealment from urban clutter

Figure 4 shows the area with likely sniper locations identified. At this stage, a visualization training tool could aid the commander in learning how to identify potential danger areas by considering the fields of observation and fields of fire from these locations, as well as the effective weapons ranges of likely enemy weapons in those locations. Subsequent assessment could identify areas with suitable cover where friendly forces could be positioned to address these threats.

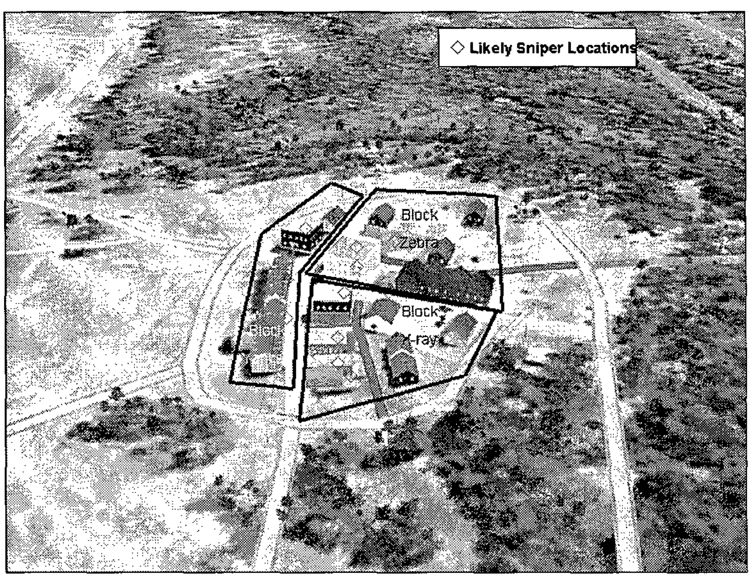

Figure 4. McKenna map with likely sniper locations.

MOUT visualization of ingress and egress routes. One difficult aspect of urban operations is the multitude of possible avenues of approach and escape in and around streets, alleyways, buildings and urban clutter. For a successful mission, the commander must clearly identify these areas and evaluate their potential advantage and disadvantage from both the enemy and the friendly perspective.

Two major goals for planning cordon and search operations include 'Project Enemy Behavior,' and 'Plan Route.' Satisfying these goals provides the commander with the battlefield situation that he must visualize prior to moving into the AO to conduct the cordon and search. Identifying routes of ingress and egress among the buildings as well as building entry and exit points allow him to plan on possible use of roadblocks or security team locations to prevent insurgents from escaping the area and to aid his forces entry and withdrawal from the area. The commander will place his reserve element where they can quickly maneuver along a route to accomplish a task, for example, to reinforce a vehicle checkpoint. Visualizing where vehicle or pedestrian traffic may impact his mission will help the commander see where security element positions are best employed. He can also identify possible locations where civilian crowds may gather and attempt to disrupt or influence the search.

Urban areas present several aspects for careful consideration including the following:

- Building entry and exit points
- Types of streets and alleyways between buildings
- Location of open areas such as parks, markets, public squares, and athletic fields
- Subterranean features such as irrigation channels or sewer systems
- Building and block patterns
- Surrounding terrain features such as wooded areas or water obstacles
- Observation and fields of fire from various vantage points, both inside of buildings and outside on streets
- Funnel areas or choke points that inhibit dispersion
- Conditions of streets or roads that might impact vehicle speed and traffic flow
- Cover and concealment along routes of ingress and egress

Using a visualization tool, the commander can learn to determine where he should emplace his forces (see Figure 5). With security augmentation from host nation militia, the commander can focus his forces on the most critical areas in his AO and assign missions to each element in force. Once he identifies the ingress and egress routes that would spill out of or originate in his sector, the commander can determine that the optimal places to place his security element is at check points (CP) 1, 3, and 5. He knows he can then assign CP 2, 4, and 6 and the wooded area between CPs 2 and 3 to the host nation militia force assisting him. At the checkpoints, the squads would control vehicle and pedestrian traffic to cordon off the area and prevent disruption to the search platoon. He can brief the search element and the reserve on the security plan and ensure that they maintain awareness of these ingress and egress routes so that they can react and stop possible escapes from insurgents. He can orient his security forces down streets or alleyways and to cover sewer points of entry as well.

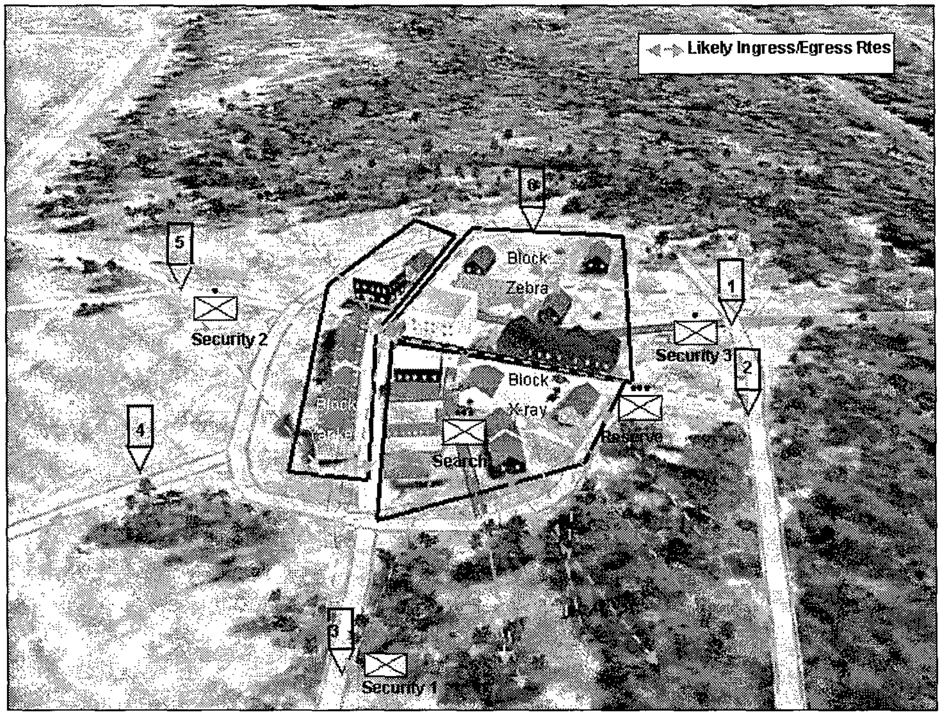

Figure 5. McKenna map with ingress and egress routes, and troop placement.

Combining knowledge of ingress and egress routes for insurgents with the sniper information, training will support the commander in visualizing the placement of his forces in relation to likely enemy sniper positions. In an urban environment (see Figure 6), he will notice that snipers from the other block areas can easily influence his AO. The training tool will sensitize him to areas of possible contact; ensuring they are observed by search and security elements. The commander will see the position of his forces and determine what elements might be more exposed to sniper fire. He can then determine how best to use available block, building and street patterns to mask movement without exposing his forces unnecessarily to enemy threats. The visualization training tool will also enable him to see where to emplace counter-sniper teams and where to orient his platoon leaders observation and fields of fire. The commander can see possible locations to position his reserve element where they can be the most responsive to his operation without being at undue risk.

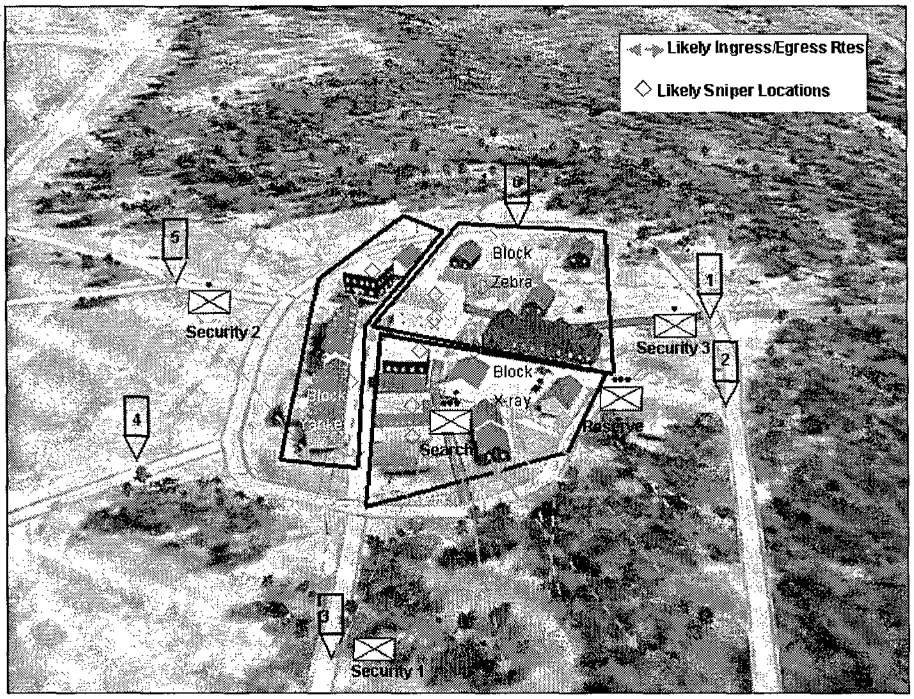

Figure 6. McKenna map with ingress and egress routes, likely sniper locations, and troop placement.

MOUT Scenario: Situation Awareness Requirements

SA is domain-specific; by this we mean that the knowledge and skills necessary to develop superior SA in one domain may be generally very different from those in another. For example, the knowledge and skills needed for a Company commander to develop good SA are significantly different from the skills and knowledge a commercial airline pilot would need to develop good SA, while dismount infantry in combat and cordon and search units use very related knowledge and skills. Not only are the tools used by the individuals vastly different, but so are the information gathering techniques, the skills required, and the knowledge bases and mental models that provide a framework for the development of SA. The first step, then, in developing a training program to improve SA within a domain, such as dismounted infantry, is to conduct some form of requirements analysis to identify the domain-specific dynamic information requirements (i.e., the SA needs) for the position of interest (e.g., the Company commander.)

An SA requirements analysis usually employs a combination of cognitive engineering procedures. Expert elicitation, observation of operator performance of tasks, verbal protocols, formal questionnaires and analysis of written materials and documentation, i.e. training manuals and checklists, have formed the basis for these analyses. To date, such analyses have been completed for many domains including fighter pilots Endsley, 1993, bomber pilots (Endsley, 1989), TRACON air traffic control (Endsley & Jones, 1995), infantry platoon leaders (Strater, Endsley, Pleban, & Matthews, 2000), Army brigade level officers (Bolstad, Riley, Jones, & Endsley, 2002), and Naval air warfare coordinators (Strater, Endsley, & Plott, 2004). A similar process has been employed by Hogg, Torralba and Volden (1993) to determine appropriate queries for a nuclear reactor domain.

Frequently, the problem of determining what aspects of the situation are important for a particular operator's SA has been approached using a form of cognitive task analysis called a Goal-Directed Task Analysis (GDTA), illustrated in Figure 7. In such an analysis, the major goals of a particular position are identified, along with subgoals necessary for meeting each goal. An example of a goal would be to identify and monitor threats, while a subgoal of this might be communicating with team members. For each subgoal, the major decisions to be made are identified. The SA needs for making these decisions and carrying out each subgoal are subsequently determined. By focusing on goals, rather than tasks, this methodology seeks to identify the information needs directly, without considering *how* the operator will acquire the information, as the method may change from one operator to another, or as new technologies are fielded. In addition, goals form the basis for decision making in many complex environments. Finally, the GDTA seeks to determine the *ideal* information needs of the operator, everything the operator would like to know, rather than just the information that can be gained with existing technologies and information sources.

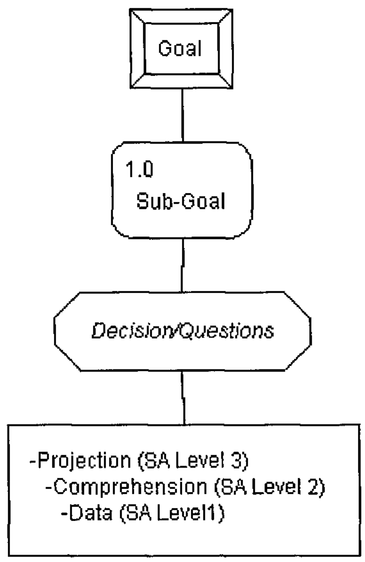

Figure 7. GDTA goal hierarchy format.

To conduct the GDTA for the initial phase of this investigation, researchers met individually with a single Subject Matter Expert (SME), a skilled and articulate Lieutenant Colonel currently in the U.S. Army Reserves as a staff officer instructor. Our SME is a military analyst with 15 years of U.S. Army infantry officer experience, who served in multiple positions from infantry platoon leader and company commander to battalion and brigade staff officer and graduated from the Army Command and General Staff College at Fort Leavenworth, KS. He is also experienced in conducting GDTAs for enhancing SA. During three interviews of approximately two hours each, the SME responded to a series of open-ended questions designed to elicit lengthy responses concerning his major goals and the decisions associated with the accomplishment of these goals for a company commander during a cordon and search mission in urban terrain. He then addressed the information needed to formulate these decisions.

Interviewers held their questions until a natural stop in the dialogue so as not to interrupt the flow of ideas. When a natural pause occurred in the narration, particular attention was taken to ascertain exactly how each piece of information is used. Higher-level assessments of the situation related to comprehension and projection were determined in this manner. The completed analysis was structured into a graphical depiction for SME review and refinement. For this GDTA, the SME and researchers then compared the results of the analysis to other GDTA information hierarchies from related domains (i.e. an infantry platoon leader on a MOUT mission) to identify any gaps in the results.

The overview page of the Company commander analysis shows the overall goal hierarchy structure, with *Secure and search assigned area* as the overarching objective (Figure 8). This is then broken down into seven primary goals, with secondary goals under each that may be employed to meet the mission objectives. Each secondary goal is later listed on a separate page in the requirements analysis, broken down into subgoals. For primary goal 1.0, *Protect the force/Avoid casualties*, five secondary goals are listed, with three of those being further divided into subgoals (Figure 9). For each subgoal, some of the questions the company commander is considering are listed, followed by the SA elements necessary to answer these questions. Figure 10 illustrates the SA requirements for subgoal 1.1.2 – *Avoid danger areas*. Listed beneath the subgoal are some of the questions that the Company commander will consider: *What is the least exposed position or avenue of approach*, and *how do I minimize the impact of danger areas?* Under these questions is a list of information that the Company commander will consider in addressing this goal, such as projected enemy behavior, areas of cover and concealment, time constraints and funnel areas.

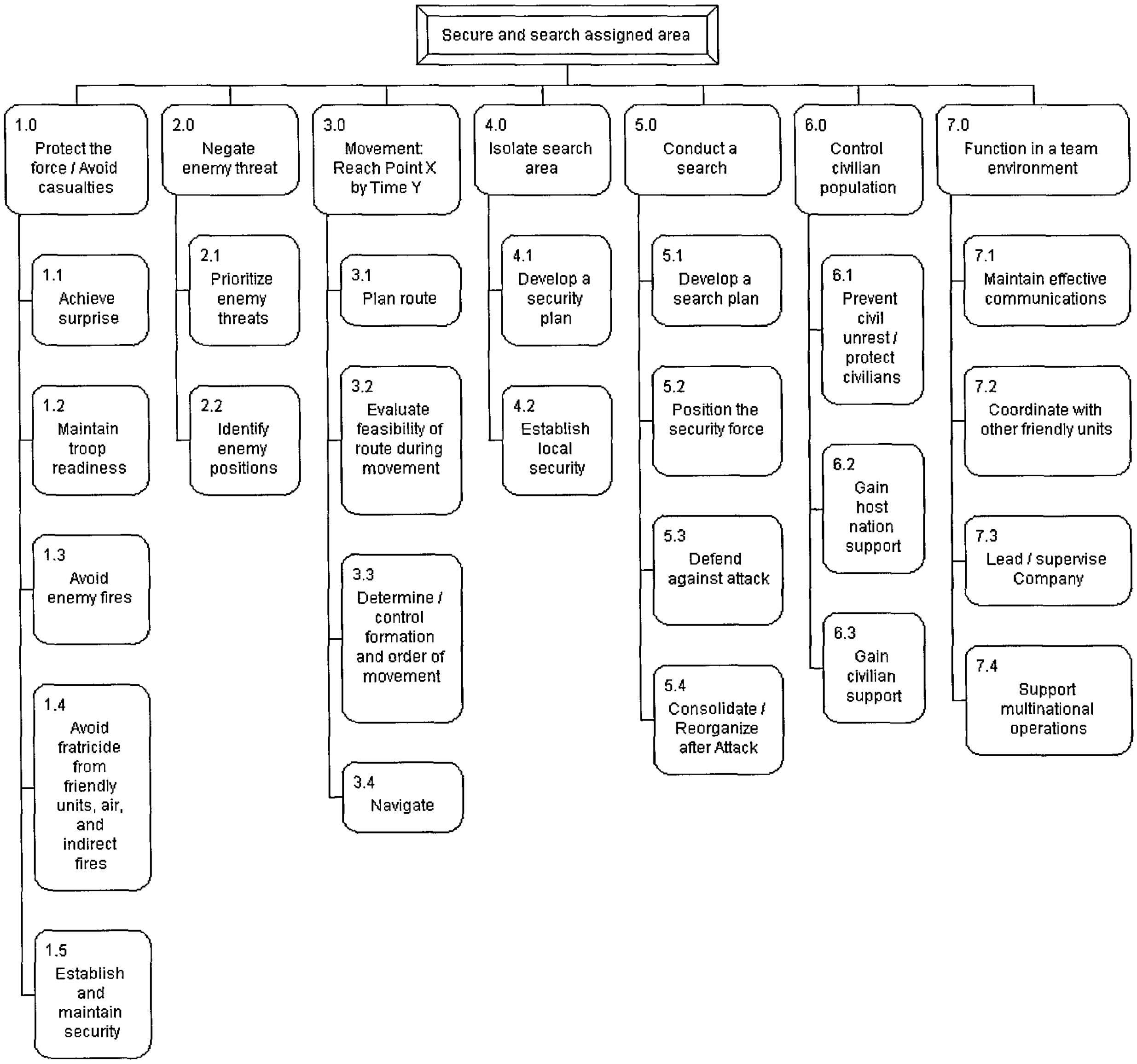

Figure 8. Overall goal hierarchy for cordon and search mission.

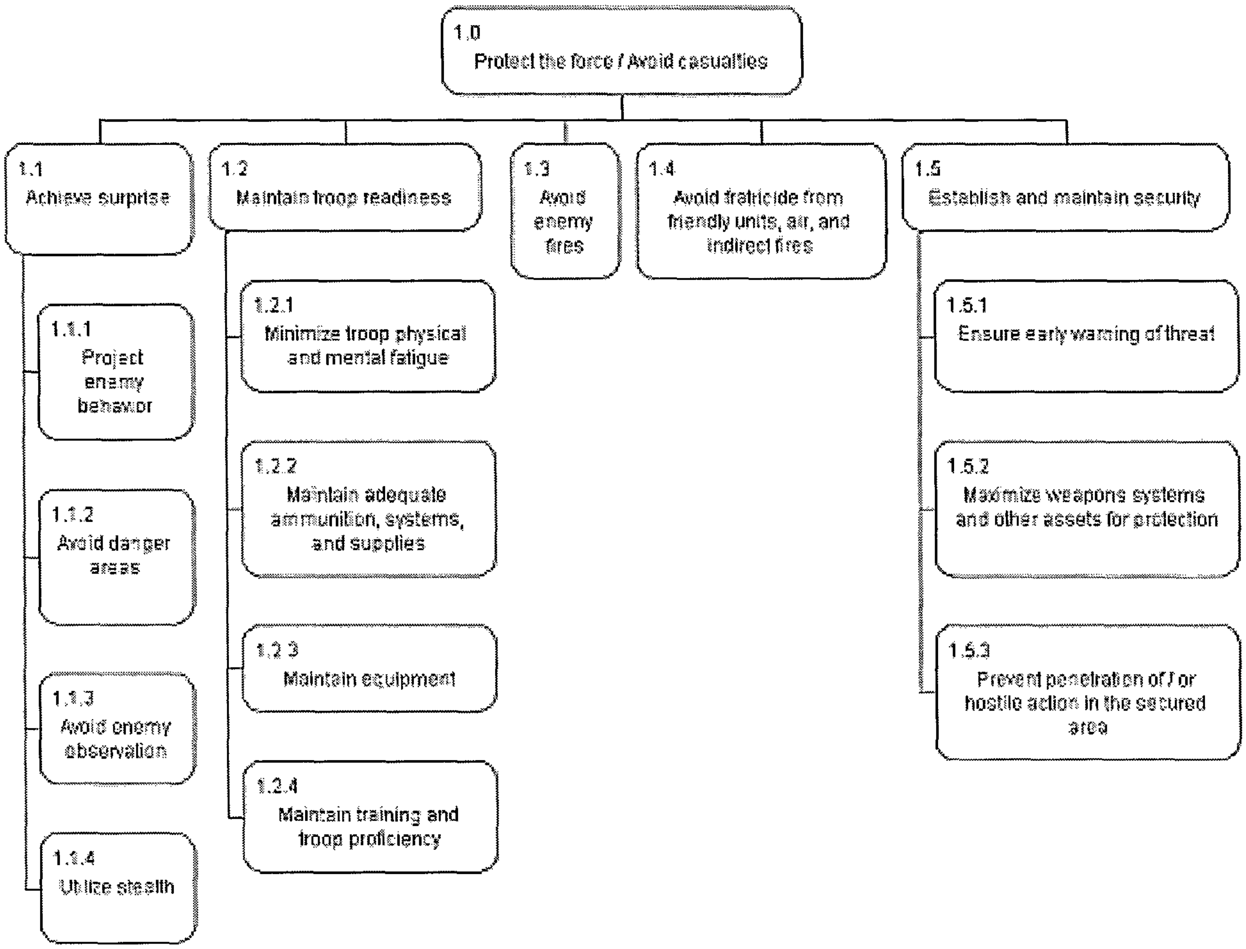

Figure 9. Primary goal 1.0 – ***Protect the force/Avoid casualties.***

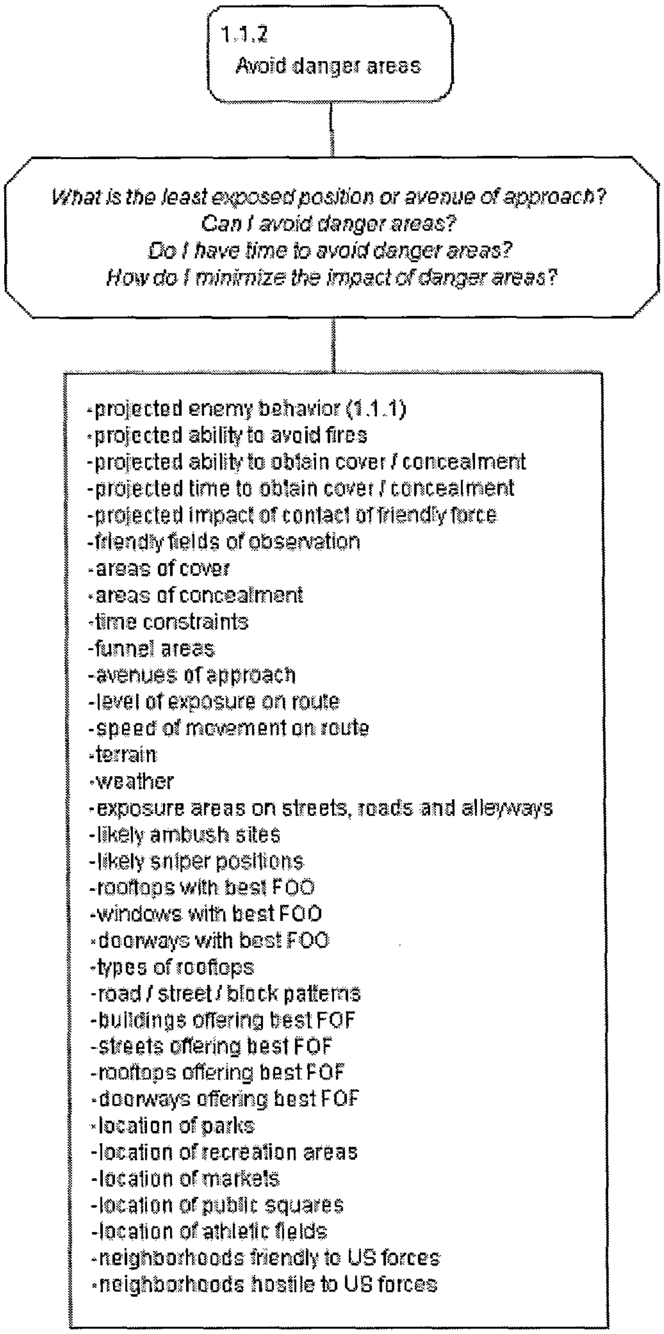

Figure 10. 1.1.2 ***Avoid Danger Areas.***

To aid in understanding the information needs, an additional SA requirements analysis was undertaken to determine the Level 1 (data), Level 2 (comprehension) and Level 3 (projection) SA needs of the Company commander. Much of the information was redundant across a range of goals, and this analysis provides a vehicle for information consolidation. The SA requirements were divided into categories for threat, friendly, civilian, supplies, mission, terrain, weapons, communications, weather, and MOUT-specific information. Table 1 shows how the information from subgoal 1.1.2 'avoid danger areas' was reorganized in this SA analysis. This table shows that for this subgoal, supplies and communications are not areas of primary concern, as no items specific to those two categories are listed. Moreover, this analysis reveals that many of the SA requirements identified in the GDTA focus on the higher-level assessments involved in understanding and projecting into the future. Lower-level data needs are often left out of the goal hierarchy for the sake of parsimony, however, this does not suggest that the lower-level information is not important, but rather that these data are useful to the extent that they support these assessments that are critical for timely decision making and action. Thus, the SA requirements analysis provides a more complete listing of the lower level SA information that support development of the higher level assessments necessary for meeting the Company commander's goals. In conjunction the GDTA and the SA requirements analysis provide the research basis to support the development of training programs targeted to improve the visualization skills to promote the development of superior SA.

Table 1. Situation awareness requirements for subgoal 1.1.2 – *Avoid danger areas*

	Level 1 SA	Level 2 SA	Level 3 SA
Threat		likely ambush sites likely sniper positions	projected enemy actions projected impact of contact
Friendly		friendly fields of observation	projected ability to avoid fires projected availability of cover/concealment projected time to cover/concealment
Civilian	civilian attitude	traffic patterns neighborhoods friendly/hostile to US forces	
Supplies			
Mission	time constraints		
Terrain	type of terrain buildings	areas of cover areas of concealment funnel areas level of exposure on route avenues of approach speed of movement likely ambush sites likely sniper positions	projected availability of cover/concealment projected time to cover/concealment
Weapons			projected ability to avoid fires
Comms			
Weather		impact of weather	
MOUT	parks/recreation areas location of markets location of public squares location of athletic fields avenues of approach cover & concealment types of rooftops block patterns street patterns pedestrian traffic civilian hostile attitude civilian friendly attitude	danger areas/exposure areas areas of cover areas of concealment funnel areas level of exposure on route avenues of approach speed of movement on route likely ambush sites likely sniper positions windows/rooftops/doorways with best observation areas traffic patterns neighborhoods friendly/hostile to US forces	projected availability of cover/concealment projected time to cover/concealment

From the GDTA, then, we learn that the company commander has multiple information requirements facing him. He must consider many different pieces of information to understand the complexity of the urban terrain and how the buildings, streets, and alley patterns impact on his movement and security. To compound the difficulty, he gets this data from multiple sources. Maps, written and verbal intelligence reports, troop observation and reconnaissance, local civilians and his own experience come together to help him paint the picture and confirm or deny the impact the terrain may have on his plan. The challenge for the company commander is to take this information, integrate it together in some fashion to effectively determine where to position his teams, how to methodically search the area, and where best to position his reserve to react to situations that arise during the operation.

In the process he must also continually consider the enemy, where enemies are likely to be positioned, with what assets and capabilities, and how that will impact the company commander's plan and mission. The company commander also receives enemy information through varied means. Text, radio and face-to-face reports of past incidents, intelligence reports from higher headquarters, observations and assessments of soldiers as they move into and around the area must be brought together to construct a mental concept of likely enemy threats. What kinds of threats (RPG teams, car bombs, snipers, IEDs and booby traps), where the threat might occur, and how the enemy may react are important areas where the commander must apply his experience and available information to ensure he takes adequate measures to protect the force. Information from graphical, textual, and verbal reports must be integrated to form a comprehensive picture of the battlespace and the challenges the commander will face. With little training provided in visualization, such an integration process relies heavily on the company commander's individual skill and experience and can, therefore be highly variable. Training that targets the company commander's ability to visualize and assess the battlefield during mission planning will increase his ability to effectively accomplish his mission. The same visualization skills that the commander has learned and exercised during mission planning will form the basis for visualizing a rapid change during mission execution, even if the visualization tools available are during the rapid Replanning are only grease pencil and acetate and not a C2 system.

MOUT Training

Many aspects of military leadership are described and taught as both an art and a science. While many important skills, such as the MDMP have become well-defined processes; battlefield visualization in support of good decision making is too often considered to be only an art. Like battlefield visualization, art practice (e.g. painting, sculpting) is usually taught as a series of "how-to" methods. But historically, as arts evolve, these how to methods become systematized and codified (e.g. the development and refinement of color theory in painting). A central goal of this STTR effort has been to examine how a combination of novel computer visualization techniques, situation awareness-centric task analysis, intelligent tutoring, and other digital information presentation and learning techniques could be used to systematize battlefield visualization, transforming it from an art to a science. This section discusses how such skills are currently taught in formal military courses (i.e. "schoolhouse" training), an assessment of battlefield needs as reported from several anecdotal accounts from Operation Iraqi Freedom (OIF), and where fundamental gaps exist between what skills are taught versus what skills are required. This work addresses visualization and decision making needs for company-level commanders in MOUT and Stability and Support Operations (SASO) environments with an emphasis on cordon and search missions.

Leadership and battlefield skills for company-level MOUT operations are taught in the Infantry Captains Career Course at Ft. Benning, via correspondence course (US Army Infantry School ACC 071 A11), and through similar courses taught for other officer specialties. While there is no specific lesson in Battlefield Visualization or the use of visualization techniques, aspects of it are taught throughout the coursework in the context of other lessons. For example, although there are training modules for Military Operations other than War, Combat in Built-Up Areas, and Tactical Doctrine that address theoretical and doctrinally correct methods for planning, preparing, and executing various operations, none of the training modules discusses the practical techniques necessary to utilize information generally and graphical artifacts in particular to develop mental models or schemata necessary to internally frame the battle situation or to develop external graphical artifacts from existing multi-source intelligence products.

There is also a somewhat disjointed organization of command doctrine reflected in current field manuals such as FM 90-10 (MOUT, Department of the Army, 1979) and FM 3-06-11 (Combined Arms on Urban Terrain, Department of the Army, 2002a). This lack of consistency carries over to joint operations (Joint Urban Operations – Enabling Concept v.86). To help bridge the gap between formal training and operational need, training circulars such as TC 7-98-1, Stability and Support Operations Training Support Package (Department of the Army, 1998), combine various doctrinal elements to address specific practical mission requirements such as for cordon and search operations. However, even these more practical training support materials do not address visualization skills in a way that can more fully prepare new officers for battle conditions. TRADOC PAM 525-70 (Department of the Army, 1995) discusses the art, science, and integration of battlefield visualization skills in a general way. It notes that computer and digital technology are essential, but it does not discuss how warfighters can or should make use of specific technologies to support visualization and situation awareness. It also does not discuss how such essential skills are best connected with the MDMP. TRADOC PAM 525-70 concedes that battlefield visualization is still more of an art than a science.

The gap between current formal training practices and operational need has been expressed in many forms and at many levels, but some of the most useful anecdotal accounts are in the form of "lessons learned". Many such accounts from OIF, Bosnia, and elsewhere have been captured, passed along, and are used to help structure in-country unit training of personnel. The Center for Army Lessons Learned (CALL) serves as a repository for many official accounts, but websites such as http://companycommand.army.mil have been formed to support the exchange of information at a much less formal level. Among the official accounts from OIF is the CALL Initial Impressions report 04-13 (Center for Army Lessons Learned, 2004) that discusses specific gaps between doctrine and operational need. One focus area for this report is Information Operations and the inability of many warfighters to fully understand information operations, the collection process, or how to integrate information at the tactical level. These issues are echoed by U.S. Marine Corps units as well (US Marine Corps, 2003) and expound further on the inability to fully understand information operations and how to separate necessary from unnecessary information. Developing better visualization skills, understanding how to visualize what is known and not known, and how such visualizations feed into the MDMP would help bridge this gap.

Among the unofficial lessons learned accounts are two that characterize a rather broad need for better visualization skills. Morgan (2004) discusses lessons learned from the perspective of an infantry company commander. Morgan stresses the need to maintain high levels of situation awareness for all operations and the ability to quickly recognize bad situations and patterns of activity. Although he concludes by stating that most of what is taught in military schools remains useful, he concedes it is not enough. To become highly effective, he recommends that company commanders conduct extensive training and rehearsals with their units using realistic terrain models and realistic missions (such as cordon and search, securing convoy routes, normal patrols, and civil-military operations) and follow every mission with an after action review. Conducting such training is the basis for forming accurate and effective mental models; conducting after action reviews is the basis for correcting and extending existing mental models. It is essential for effective commanders to be capable of forming such mental models themselves, and to be able to teach those skills to others.

Olmstead (2003) also presents an unofficial discussion of lessons learned that supports the views of Morgan. Among many issues, he discusses several key gaps between formal training and operational need that could be addressed by better visualization training tools:

- Dismount drills for mechanized units – While there exist good standard operating procedures (SOP)s for dismounting under various circumstances, recognizing the current situation and how it maps into a specific action drill could be improved by visualizing different situations and understanding salient recognition features.
- Communication and navigation in MOUT environments – Understanding when standard communications SOPs will not be adequate (e.g. within-building or subterranean operations), understanding how to successfully visualize communication requirements, and understanding how and when to augment SOP with ad hoc solutions (e.g. line of sight communication chains). Additionally the ability to integrate and use multiple information types (e.g. map-based and satellite) is a useful skill for unknown environments.
- Convoy and team operations – Visualizing overwatch locations, potential combatant and sniper locations, lines of sight, and other important spatial aspects of MOUT missions is critical to effective planning.
- Training to ROE (Rules of Engagement) – Understanding how ROE will affect mission conduct is an important aspect of planning and preparation. Visualizing potentially hazardous situations and locations is critical to understand when the ROE should change.
- Cultural training – Using graphical and other means to better understand the operational environment, normal patterns of activity (e.g. daily prayer times), and abnormal conditions (e.g. a freshly shaved beard can indicate an expectation to die) are essential to situation recognition and maintaining high levels of situation awareness.
- How to develop actionable commanders critical information requirements (CCIRs) and collection plans – Visualizing available information, information needs, information gaps, and their connection to CCIR and battlefield decisions are critical skills for refining CCIRs and collecting sufficient information to make effective and timely decisions.

While Olmstead does not make a connection to technology to address these gaps, it seems clear that utilizing digital technology and developing courseware that specifically addresses these issues has a strong potential.

Review of Battlefield Visualization, Military Decision making, and Information Management Literature

Battlefield Visualization is a three-step command process whereby the commander develops a clear understanding of the current situation, envisions a desired end state, and visualizes the sequences of activity that will move his force from its current situation to the desired end state (Department of the Army, 2003a). As shown in Figure 11, the foundation of battlefield visualization is the information loop, which consists of defining the CCIR, collecting data related to those requirements, and transforming collected data into situational understanding (Department of the Army, 2003a). This final transformation process has traditionally been associated with information fusion. The process of decomposing high-level information needs into fine-grained collection needs could be called an "information fission" process.

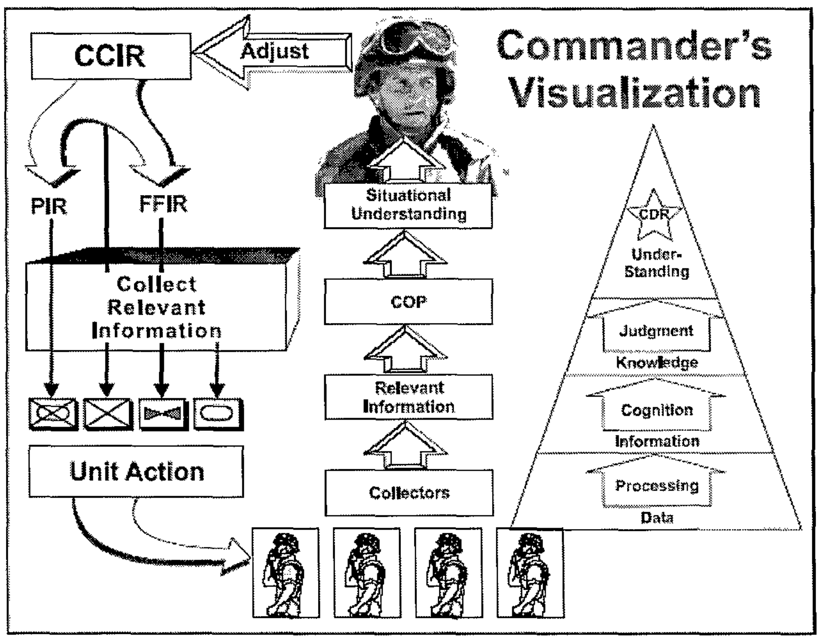

Figure 11. Commander's battlefield visualization information flow.

To help accomplish the planning aspect of Battlefield Visualization, the Military Decision making Process (MDMP) is a detailed, regimented sequence of steps for developing an operational plan to accomplish mission goals (see Figure 12). The MDMP starts with the receipt of a mission from higher command, steps through the process of analyzing the mission and developing a course of action (COA) through analysis and war gaming, and concludes with the production and dissemination of an OPORD to the unit. At the Unit of Action level, the commander would be assisted in this process by a command staff, who commonly provide five basic functions to commanders in support of reconnaissance, security, offensive, and defensive operations (Department of Army, 1996):

- Provide timely and accurate information
- Anticipate requirements and prepare estimates
- Determine courses of action and make recommendations
- Prepare plans and orders
- Supervise execution of decisions

Figure 12 illustrates the steps involved in the MDMP. This process lays the foundation for decision making during execution of the OPORD, by specifying points in the execution plan at which decisions (i.e., selections of pre-planned "branches") must be made.

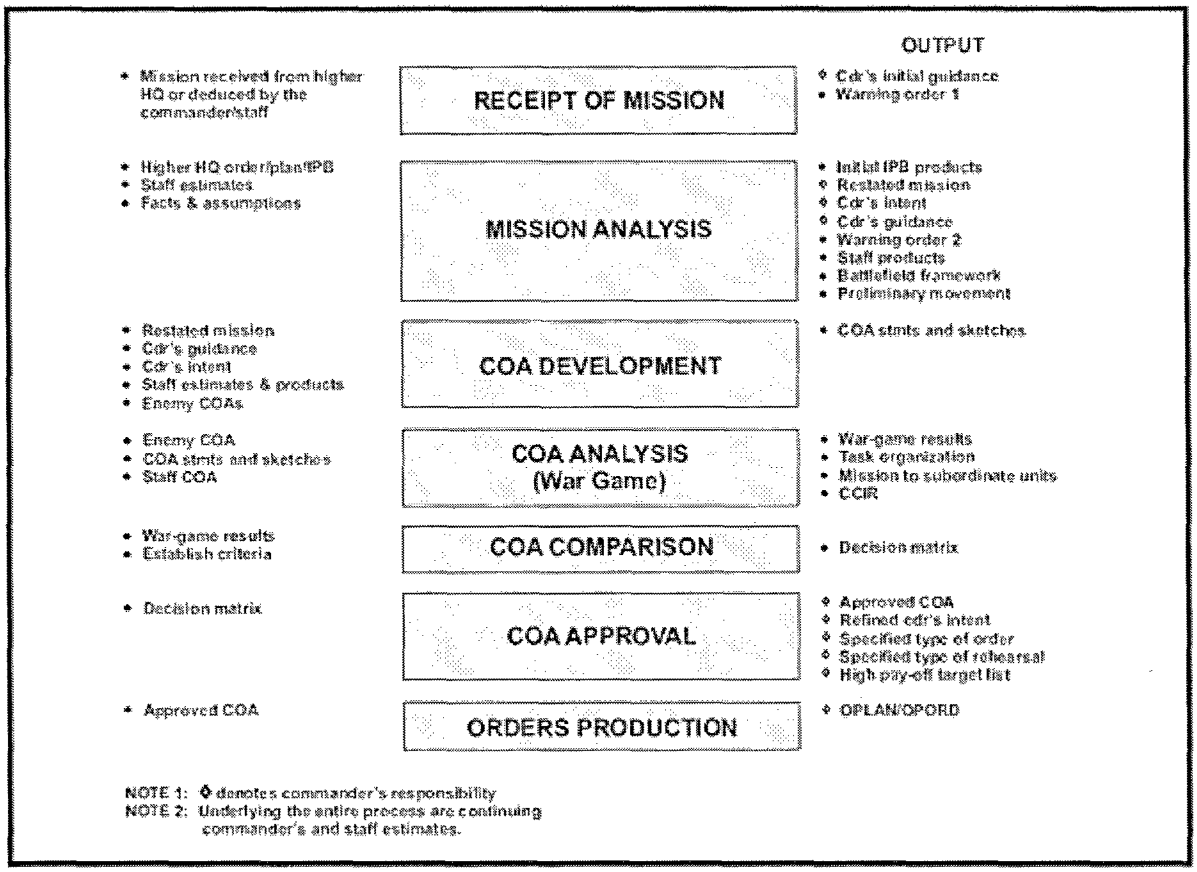

Figure 12. The staff inputs and outputs in military decision making process.

As can be seen in Figure 12, one output of the MDMP is the commander's critical information requirements (CCIR) (Department of the Army, 1997). Doctrinally, CCIR includes Priority Intelligence Requirements (PIR), Friendly Force Information Requirements (FFIR), and (somewhat adjacently) Essential Elements of Friendly Information (EEFI). This categorization helps defined how information requests are constructed by the commander and reported by elements in the field. The ability for the commander to determine their information needs and be able to define them in a manner that is actionable is critical to their ability to monitor the battlefield and to integrate battlefield observations with their situational knowledge and general military knowledge.

While TRADOC (Department of the Army, 1995) describes the need for training, and the requirement including training with technological tools, it does not specify the role of these tools in the training process. It is clear, though, that there are at least *two major roles* of technological tools in the battlefield visualization process. First, training is required to support the developing visual representations of the current battlefield situation that support situation awareness and pattern identification. Regardless of the digital display technology in theater and available to commanders, technical tools can be developed to support the development of internal representation construction expertise. Second, technological tools can be developed to support and improve the construction and analysis of visual representations based on real-time COP and CCIR information feeds. These tools would support the commander in theatre and would also require appropriate training.

Review of Cognitive Support for Visualization Literature

External visual representations. In addition to the work being done in optimizing a data-set display based on its perceptual features, there is a long tradition of humans designing visual representations to support higher-level communication and reasoning. These representations use a range of visual depiction styles, showing concrete visible things, and graphical grammars, representing invisible abstract concepts. (Tversky, 2001) Early examples include drawings, paintings, maps, and petroglyphs. More contemporary examples include photographs, television and movie images, geographic information system (GIS), radar and meteorological displays, as well as 1st and 3rd person computer game screens (see Figure 13). Since depictions are based on concrete objects or locations in either the real or a simulated worlds they tend to have strong spatial alignment with that world and can be viewed as a structured viewport into that world. This viewport does not have to provide an exact photo-realistic view, however. Research and commercial systems have explored many ways to add additional information to a depiction by manipulating image features including color or luminosity coding screen regions, smoothing road networks, or adding or removing specific terrain feature layers.

Figure 13. Satellite image of the Al Salam Palace in Iraq as a representitive conteporary depiction.

Historically, graphics evolved out of depictions to communicate concepts that were difficult or impossible to directly depict, such as proper names, abstract entities, causality, quantifications, and negations (Tversky, 2001). Contemporary graphic forms include logic diagrams such as those devised by Euler and Venn (Shin, 2002) and information graphics such as bar charts, box plots, time lines, flow and organizational charts and network diagrams (Harris, 1999) The SASO flow diagram (Department of the Army, 1997) shown in Figure 14 is a typical example of an information graphic. While graphics acquired the advantage of being able to express the abstract concepts associated with SASO, they have lost the transparency of realistic depictions. In addition, while information graphics usually have a strong internal spatial orientation, such as vertical and horizontal axis, this orientation only has metaphoric or analogic reference to any external world. The implication of this loss of representational transparency and the lack of external spatial referents is that, while graphics provide a range of benefits, any use of graphics generally requires specific training. Their meaning, unlike that of a depiction, is not automatically meaningful to the observer. Training and practice are required to render graphics intelligible.

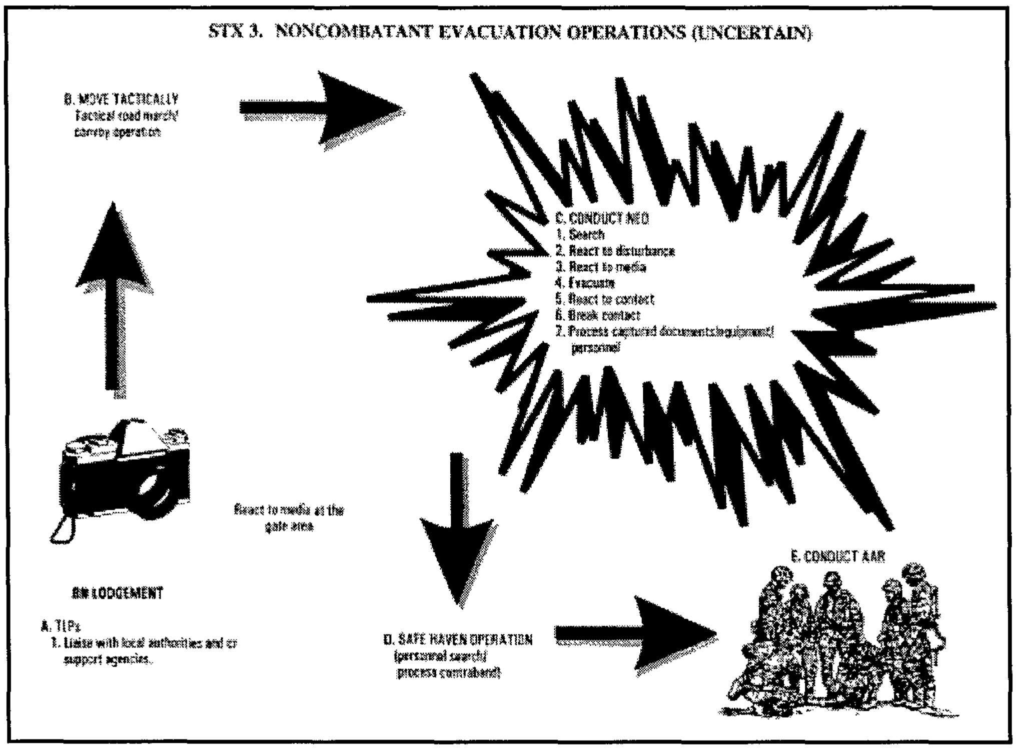

Figure 14. Stability and Support Operations (SASO) noncombatant evacuation operations flow diagram is a representitive contemporary information graphic.

When appropriate, combining purely visual depictions and graphics can increase the expressive power of the representation by leveraging the strong spatial alignment and ease of interpretation of the depiction with the abstract expressive power of the graphic. This approach is often taken in Intelligence Preparation of the Battlefield, where maps and satellite imagery are annotated with geometric areas of interest (See Figure 15; GlobalSecurity.org, 1994) and military Course of Action sketches (see Figure 16; Department of the Army, 1997), where abstract time-based operational graphics are annotated on local terrain maps.

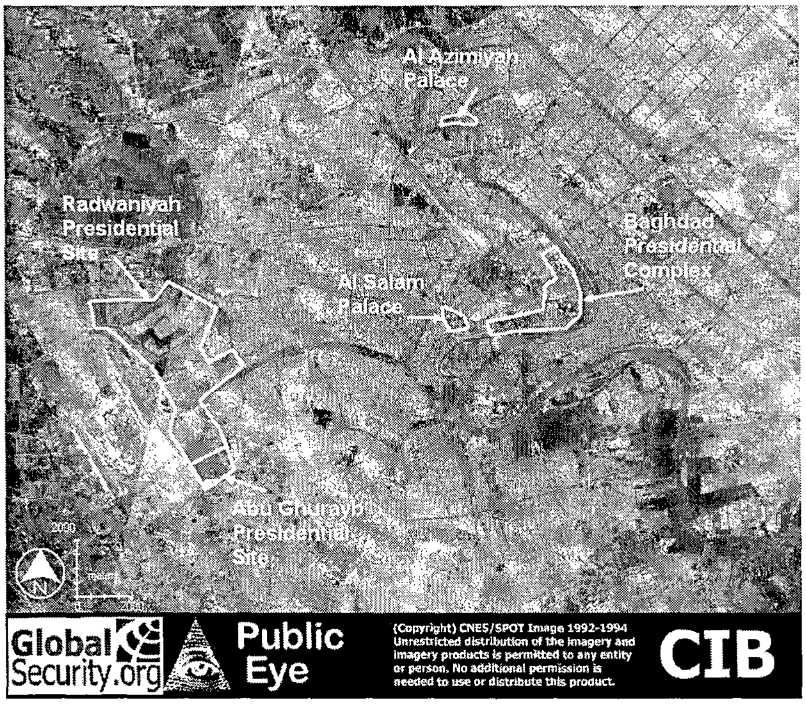

Figure 15. Satellite map depiction of Baghdad using graphics and text annotations to define regions of interest.

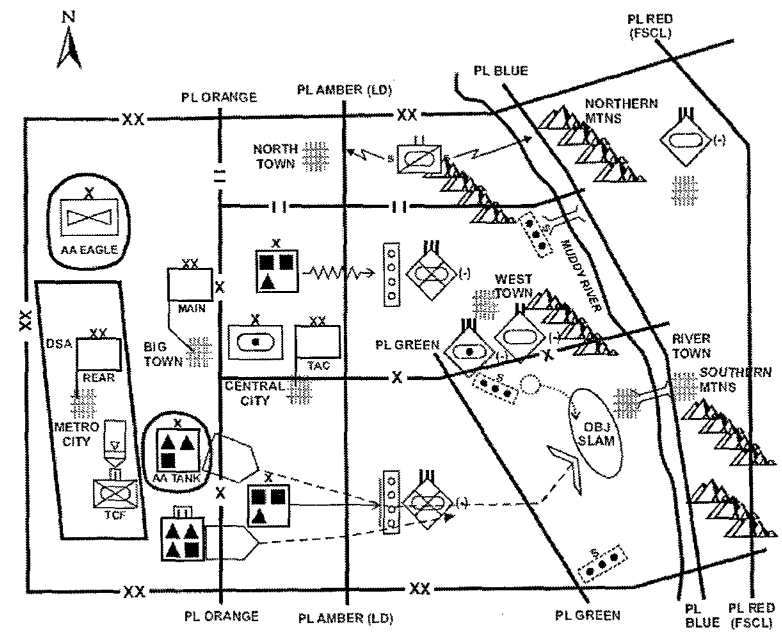

Figure 16. Course of action sketch overlays a map depiction with military operational graphics including entity and region identifications and temporal flow markers.

Benefits of cognitive representations. Researchers in cognitive psychology, mathematics, and a range of other disciplines have identified a number of basic principles that underlie the construction of external visual representations that support improved human reasoning or task performance. These principles generally focus on two main points. The first point is that representations can improve computational efficiency (Larkin & Simon, 1987) by making features more easily recognizable, making information more explicit, searchable, or interpretable. The second point is that representations can improve domain learning characteristics (Cheng, 1999) by providing the learner with an external representation that encodes all relevant features of a problem space and helping to promote the integration of those features. Table 2, below, is adapted from and extends (Woods, 1994) and presents a set of core performance and learning issues that can be supported by carefully constructed representations.

Table 2. Value of external representation in supporting human task performance and learning

Task Performance or Learning Issue	Value of Representation
1.Problem Structuring	A good external representation is constructed in a form that allows different strategies to be used. For example, maps are structured to allow spatial calculations such as relative distance and areas of effect to be made easily.
2.Overload/workload	A good external representation reduces or attenuates cognitive effort by allowing processing that may be parallel, perceptual, or reentrant. In addition, a good representation can reduce demands on memory or dependencies on attention.
3.Control of Attention	A good external representation can draw attention to specific regions of the representation to support important data properties. A good external representation can also hold a viewers attention, allowing them to conduct more in depth analysis.
4.Secondary Tasks	A poor representation can create unnecessary secondary tasks, such conversions between scales and correlating with unrepresented data ranges. A good representation can create or allow beneficial secondary tasks that might be skipped, such as consistency and cross-checking results.
5.Effort	A good representation can reduce effort for a specific task-context.
6.Communication & Coordination	A good representation allows others access to the problem solving process and intermediary results.
7.Guided Interpretation	A good representation supports the range of valid interpretations that can be made of a set of information and does not support improper interpretations

Internal Representations. The external visual representations described above are directly related to human internal representations, also known as mental models or schema. There is a core relationship between human internal representations and external representations of problem areas. This relationship has three principle components (Norman, 1983):

- Belief System: The belief system that forms the schema has been acquired through observation, instruction, or inference.
- Observability: There is a correspondence between parameters and states in the humans' schema and the parameters and states that the human can observe in the external world.
- Predictive Power: The purpose of the schema is to enable limited prediction of future states and parameters. This means that the model learned by the human, to be useful, must have the ability to generate useful predictions. By implication, the external belief system the human is engaged with must be structured to support the same predictions and to enable the human to make those predictions.

For example, the COA graphic (see Figure 16, on page 30) layers a complex information graphic on top of simple, stylized, map depiction. The authors and readers of this diagram need specific training in understanding the syntactic content of the individual pictograms and the semantic meaning of their relative locations on the base map. The graphic presents a very specific class of tactical mission pictograms[2] that mark the location of concrete objects, including friendly units and town locations, abstract geographic areas, such as objective areas, and abstract process flow indicators, such as advance and reconnaissance arrows and lines of advance. This graphic both reflects and informs how the military understands courses of action and the critical behaviors of Army units and renders the graphic authors understanding of the current world and possible future world explicit and observable. The graphic has a strong spatial and temporal orientation, articulating the behavior of entities over time and space. The graphic only reflects intent, however, and not a scripted reality. COA diagrams have only a limited predictive power, but a strong interpretive and communicative power.

One critical point is that schemas are not simply internalized versions of external representations. Schemas are flexible and active, automatically filling in missing information, generalizing from the past. They are continually modifying and adapting interpretive states (Norman, 1986b) that guide how we think understand our environment. These correspondences, then, apply broadly to the entire environment and not just to visual representations. In the COA example, a trained reader can identify detail not available in the external representation and apply general knowledge to fill in those gaps.

The impact on visual representations, though, is clear: external representations must support the construction of mental models with appropriate expressiveness and predictive power. A COA map that expresses historic meteorological data but not planned actions would not be appropriate. In addition, external representations must provide indicators of current parameters and states in a manner that corresponds with that model. Finally, the external representation must

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[2] Standard military terminology refers to these pictograms as "graphics." We have used the more specific term "pictogram" here to avoid confusion with the broader class of information graphics.

support the interactive construction, modification, and interpretation to support the performance and learning issues described above.

There is a large challenge, then, in designing external visual representations that have the right mix of concrete depiction and abstract graphics laid out in a manner that supports the right class of calculations, search and inferences and populated with data that properly reflects the external and internal worlds. These are significant challenges, particularly when we consider the task dependent nature of representations. Table 2 (see page) listed a number ways that external representations impact task and learning performance. The implication of this list is that task specific representations better mesh and support schemas and improve task and learning performance. The challenge, then, is to ensure that a human engaged in a performance or learning task either has available or can construct an appropriate external representation.

Basic Visualization Skills. In pursuing this research we have developed a set of basic skills that are required to support the construction, manipulation and usage of external representations (see Table 3) and their positive usage in internal model formation and decision making (see Table 4). These skills, we believe, are both applicable to the user of a visual representation and trainable in a general way that will support transfer of skill across a range of tasks and technologies. Training these skills requires a focus on the information and computation needs of the task in question and understanding the nature of visual grammar such that representations can be constructed that meet these requirements.

Table 3. Skills for External Representation Manipulation

1. Identify their current information needs 2. Select an appropriate visual artifact 3. Interpret the artifact, determining: • What classes of information it contains • What classes of inference it supports • What classes of information and inference are *not supported* 4. Manipulate the artifact to put it in a state that enables the desired information to be extracted and inferences made

Table 4. Skills for Internal Schema Construction

1. Extract relevant information from the prepared visual artifact 2. Convert the information into a form that fits their existing mental schema, including: • Transforming information from one representation or orientation into another • Aggregating discrete information chunks • Refining the existing schema (as necessary) 3. Draw inferences from new knowledge to support decision making process

Visual language theory suggests that humans process diagrammatic graphics in a manner similar to natural language and that visual languages, including all the graphics examples above, have similar structure including a visual syntax, semantics, and pragmatics (Narayanan & Hübscher, 1998). Syntax describes the grammatical form of the language: what elements it contains and how those elements are structurally organized.

Semantics describes how statements made with the language are interpreted, and what interpretations are valid. Pragmatics describes how we can use the meaning of the statements to achieve specific goals.

For an example, consider the MOUT Intelligence Preparation of the Battlefield incident overlay map below (Medby & Glenn, 2002, see Figure 17). Proper interpretation of this map requires a thorough knowledge of the syntax, semantics, and pragmatics that were assumed in its construction. The map syntax defines:

1. *The type of marks used to encode roadways of different sizes,* i.e. lines of different weights where an increase in weight corresponds to an increase in road carrying capacity and/or lane size.
2. *The types of marks used to encode roadway names and roadway types,* i.e. full text of a specific size to note urban streets and larger text in a circle to note a highway system.
3. *The types of marks used to encode incident data,* i.e. ● for ambush, ★ for bombing, ☐ for murder, and O for kidnap.

The incident overlay map semantics shows that there are twelve individual incidents in this region in the time frame recorded and that there is one cluster of bombings, one cluster of murders, two clusters (or one large cluster) of ambushes and kidnaps. The map pragmatics supports historic functions, including the recording of incident data and analytic functions, including the identification of incident locations and incident patterns.

It is equally important to understand what the visual language used in this map does not support. While the map implies that it records incidents over a limited period of time, the map syntax provides any marks that would date the individual incidents in the map or the duration of time covered by the map itself. From a semantics perspective then, it is impossible to extract temporal patterns, such as inferring the direction that the bomber might be moving through the city. From a pragmatics perspective then, this map is inappropriate for identifying temporal patterns.

RANDMR1287-6.5

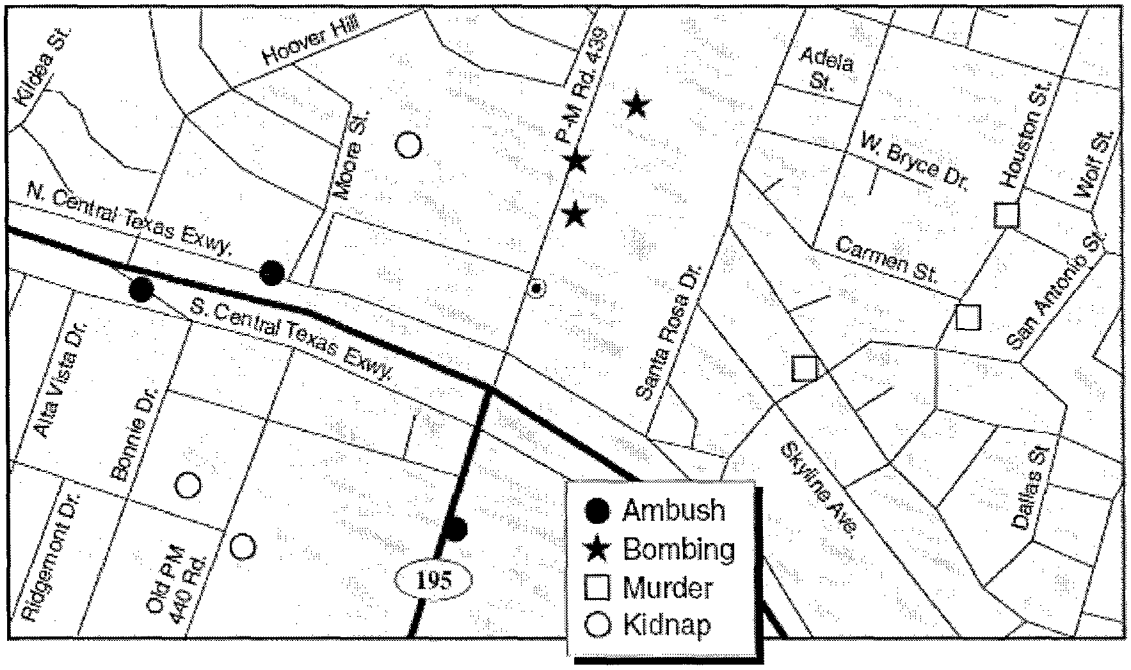

Figure 17. Interpreting this MOUT Incident Overlay Map requires understanding very specific syntax, semantics, and pragmatics

Even more critically, this map only provides syntactic markings that show positively identified incidents. The semantic implication is that any location without a marking has had no relevant incident within the time period of the map. This may be a false inference, but one common to map based representations. There are a number of reasons why relevant information may be unreported, including lack of observer or lack of observer motivation or capability to report the incident. This specific issue can have great impact on a military map, where enemy units are marked based on sensor or reconnaissance observations. The fact that an area on the map has no enemy units marked may be simply that the area in question is outside of sensor range or that no reconnaissance team has coverage in that area. Unfortunately typical military maps, such as the one in Figure 17, have this breakdown between actual map syntax and the apparent semantics. This can be contrasted to the National Oceanic and Atmospheric Administration's National Weather Service (NOAA 2005) radar image below (see Figure 18). The syntax of this map includes marks for meteorological radar sightings as well as marks that describe the limits of radar coverage.

While the examples described here are drawn from computer rendered mapping and display systems, the issues at hand are not inherently technological. The same issue could arise on a map annotated with a grease pencil in an in-theatre command vehicle. Instead, it highlights a common visual language syntactic and semantic breakdown that can form between external representations and internal schemas. It also points to the potential benefits that training can provide. Once made aware of this representation problem and the methods to detect it in other representations, we would expect that the knowledge would transfer to other similar representations.

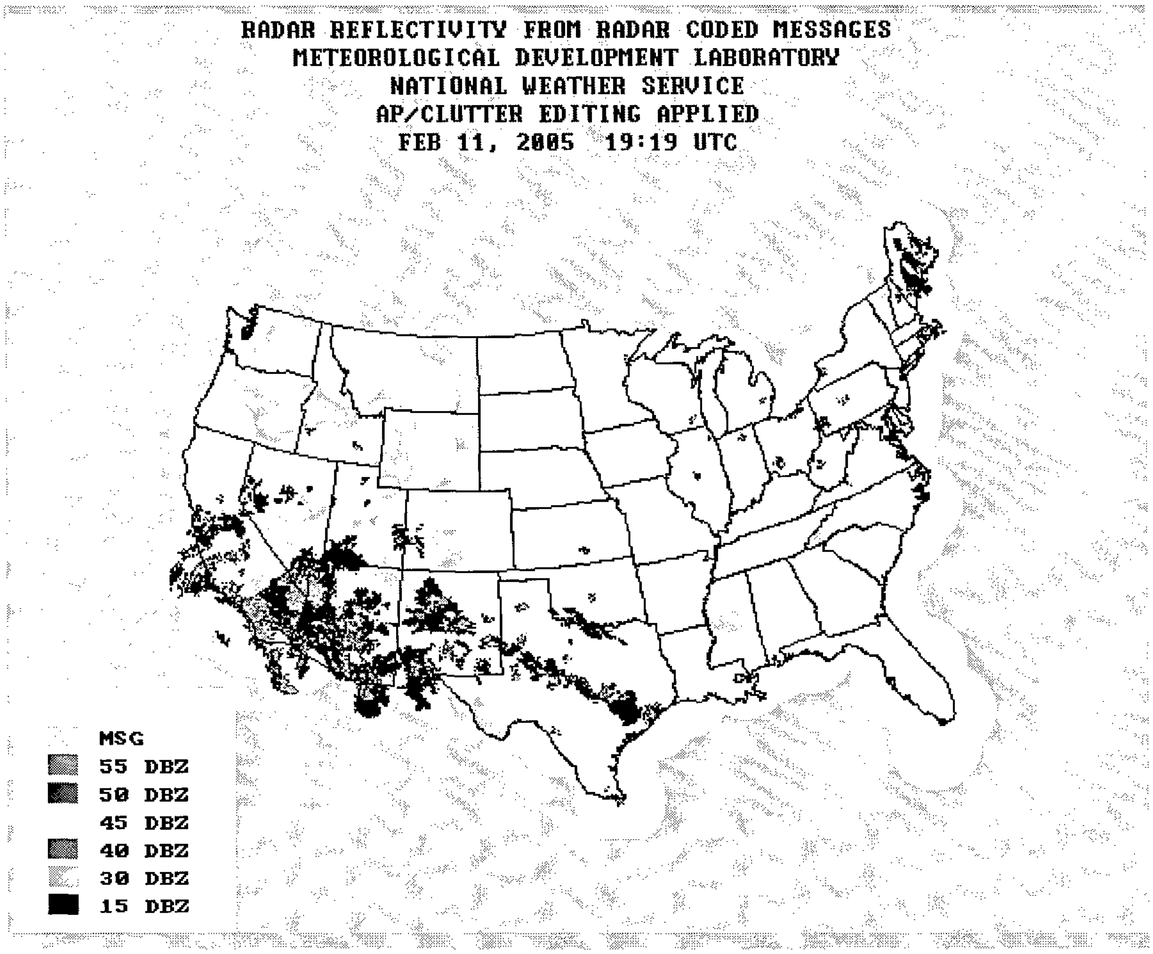

Figure 18. A National Weather Service radar image with visual syntax describing marks for radar sightings and radar coverage

Review of Educational Technology Literature

Learner-centered design vs. user-centered design. The MAVEN-SA project's desire to develop a system to train company commanders in battlefield visualization skills requires a strong focus on a learner-centered design approach. A traditional user-centered design (UCD) approach is used when designing software to assist users in their work (Norman, 1986a). The target audience (the user) already understands the basics of the work practice but needs a tool to help them complete their work more easily and effectively. The user is not necessarily trying to learn about their work through use of the tool. In fact, UCD tool designers often work explicitly to remove the necessity for users to learn anything, believing that users wish to minimize learning requirements (Carroll and Rossen, 1987). The design process must address the conceptual gulfs between the user and the tool (Quintana, Krajcik, & Soloway, 2003; Quintana, Krajcik, & Soloway, 2001). More specifically, the execution of actions on the tool must be straightforward and consistent with the user's goals, and the evaluation of the state of the tool must be understandable. UCD designers often conceptualizing tool use as a problem solving task where the problem solving is rendered as simple and well supported as possible (Card, Moran and Newell, 1983). These usability issues tend to be the primary focus of UCD.

On the other hand, a learner-centered design (LCD) approach is used when designing software to not only assist users in performing some unfamiliar task, but also to help them learn the knowledge and skills involved. The target audience in this case (the learner) has unique needs (Soloway, Guzdial, & Hay, 1994). They need support to engage in the new processes, to make sense of the new content, and to articulate their developing understanding. Although the design process must address issues of usability, it must also address the conceptual gulf between the novice and the expert (Quintana et al, 2003; Quintana et al, 2001). An analysis of the learning goals and tasks and an understanding of the learner's knowledge state reveal what will be difficult for the learner. Good learner-centered tools provide needed guidance and support so that the learner can engage in the new, unfamiliar task while gaining expertise.

Educational software informed by theories of learning. Over the years, many types of software have been developed to support student learning. The various types of educational software can be easily categorized according to their underlying theories of learning. The following summary of educational software approaches shows a chronology of learning theories that have direct implications for the kinds of knowledge and skills that can be taught (Quintana et al, 2003). Because the visualization skills that the MAVEN-SA project is aiming to teach are complex cognitive processes, certain approaches are more applicable than others.

Behaviorist approach to educational technology: Teaching machines. B. F. Skinner (1958) viewed learning as a "programming" process whereby a person's externally visible behavior could be shaped through a conditioning system of rewards and punishments. This behaviorist school of thought led to the development of a class of "teaching machines" often referred to as computer-based training (CBT) or computer-aided instruction (CAI). Immediate feedback was perhaps the most prominent feature of such software tools. Learner's responses are compared to pre-programmed answers and appropriate positive or negative feedback is given. In addition, a pre-programmed rubric is used to determine whether the learner has successfully learned enough (i.e., gotten enough correct responses) to proceed to the next task. According to Beck, Stern, & Haugsjaa (1996) here is no mechanism to evaluate the learner's knowledge or needs beyond this shallow level.

The behaviorist approach is only useful in cases where the tasks are narrowly defined and have clear answers. Examples of behaviorist software include many educational games and "flash card" type software. Because educational reform efforts are calling for an emphasis on higher-level thinking skills and more open-ended problem-solving tasks, behaviorist software is no longer popular in current educational software research and practices (Anderson, Reader, & Simon, 1998).

Information processing approach to educational technology: Intelligent tutoring systems. In contrast to the behaviorist approach that considers only observable behavior, the information processing approach considers models of cognition that are based on the idea that "certain aspects of human cognition involve knowledge that is represented symbolically" (Anderson, 1983). Rules can be applied to the representations to manipulate the knowledge, generate new knowledge, or make inferences. Human cognition can then be represented symbolically. Programs using these representations and rules can then be written as models that simulate human problem-solving behavior.

The defining feature of intelligent tutoring systems (ITS) is that they carefully oversee a learner's work to provide needed guidance. ITSs incorporate a rule-based expert model of the target skill that is used to monitor and guide novice learners as they engage in the new activity. The intent of an ITS is to model the actions and interventions of a human tutor which is the most effective means of instruction (Bloom, 1984). The ITS uses information about the task and the current state of the learner's knowledge of that task to make instructional interventions (Corbett, Koedinger, Hadely, 2001). The pedagogical nature of these instructional interventions is quite limited in nature. The model-tracing approach of many ITSs forces the learner to proceed in steps of a specified grain size (corresponding to the underlying rules) that constrains the progression of the learner's actions. If the learner makes a recognizable error (which has been pre-programmed as a buggy rule in the system), an error message is presented to explain why the action is in error. If the learner asks for help, a message is presented to guide the student toward the correct solution path. These error and help messages are not general, but instead are very context specific as they are generated based on a matching of the learner's solution with the underlying model of expert solution (Anderson, Corbett, Koedinger, & Pelletier, 1995).

The information processing approach is useful in cases where the representation of the domain knowledge has a significant rule component. That is, the domain must not be primarily declarative knowledge with limited inferential reasoning (Anderson et al, 1995). This may seem constraining, but over the years there have been a wide variety of ITSs developed in a number of domains including geometry, medical diagnoses, mammography interpretation, physics problem solving, computer programming and algebra proofs.

Social constructivist approach to educational technology: Learning environments. The social constructivist approach is the basis for many current educational approaches in science (Singer, Marx, Krajcik, & Clay Chambers, 2000). The underlying theory about how people learn has two important pieces. First, the social piece asserts that "knowledge is… in part a product of the activity, context, and culture in which it is developed and used" (Brown, Collins, & Duguid, 1989). This contextualized view of knowledge implies that learners must participate in social context that reflects the culture of the practice. Second, the constructivist piece asserts that learners must be actively engaged to make cognitive connections between their existing knowledge and the knowledge they are learning (Papert, 1993; Piaget, 1954).

Because constructivism is a "theory of knowing" and not a "theory of teaching," there is no one specific constructivist approach (Bransford, Brown, & Cocking, 2000). As a result, the products of the social constructivist approach are complex learning environments rather than specific types of instructional systems. Learning environments can include multiple components that work together to support the learner as they mindfully engage in and learn a new practice. Wilson (1996) defines such a learning environment as: "a place where learners may work together and support each other as they use a variety of tools and information resources in their guided pursuit of learning goals and problem-solving activities."

Designers of learning environments are guided by a set of seven important pedagogical goals (Honebein, 1996).

1. Learners must be given some autonomy in the learning process so that they are actively engaged in the knowledge construction process.

2. Learners must experience multiple ways to think about and solve problems to enrich their understanding.
3. The learning must be situated in a realistic and relevant context to increase the likelihood of transfer from the learning context to actual practice.
4. The learner must be given some ownership in the knowledge construction process so that the role of the instructor becomes supportive rather than primary.
5. Collaboration must be encouraged so that the social interactions and roles of the practice can be realized.
6. Multiple modes of representation must be employed to demonstrate different perspectives and enrich the learner's knowledge.
7. Metacognitive processes must be encouraged so that the learner can inspect and reflect upon his/her own thinking.

Depending on the context of the targeted practice, these goals may be instantiated in a variety of ways, leading to learning environments that look very different on the surface. A learning environment may be comprised of multiple components (e.g., teacher, curriculum, and ITS) that work together to support and guide the learner. Although it is possible to construct a learning environment that does not incorporate technology, it is more practical to include technology so that the driving goal of one-to-one instruction can be more readily realized.

The social constructivist approach allows one to tackle more open-ended and exploratory tasks than either the behaviorist or information processing approaches. The very nature of these open-ended and exploratory tasks, however, requires the development of more complex cognitive processes on the part of the learner. Considering the potentially great gap between the novice learner and the targeted practice, significant structure and support is needed for the novice learner to effectively engage in the new practices.

Scaffolding. In all of the approaches to educational technology described above, learners are faced with novel tasks that are beyond their abilities. The intent is that with support they will learn to do them. This basic strategy is theoretically based upon Vygotsky's (1978) zone of proximal development (ZPD) concept. ZPD is defined as the zone of activity in which a person can produce with assistance what they cannot produce alone. Wood, Bruner, and Ross (1976) first introduced the idea of scaffolding as a process to take advantage of the ZPD. They define scaffolding as a process where assistance is provided to enable learners to successfully perform tasks that would be otherwise be too difficult. Pea (2004) points out that a fundamental aspect of the scaffolding process as an instructional strategy is fading. If the supports provided to the learner do not fade over time, the learner may become reliant on them and never achieve autonomous performance that is the goal in an instructional setting. Situations in which supports remain in place and continue to assist performance must be considered to be distributed intelligence (scaffolds-for-performance) not independent performance (scaffolds-with-fading) (Pea, 2004).

Although various researchers have proposed guidelines and strategies for implementing scaffolding, there exists no agreed-upon theory of pedagogical support nor mechanisms to describe successful scaffolding approaches (Quintana et al, 2004). Guzdial (1994) first proposed three ways software could provide scaffolding to provide needed structure for difficult tasks:

communicating process to learners, coaching learners with hints, and prompting for articulation and reflection. Pea (2004) has recently proposed three scaffolding strategies: constraining tasks to reduce the degrees of freedom and increase chances for successful performance, focusing learner attention by highlighting relevant task features, and modeling advanced solutions. Although these guidelines for designing scaffolds are all theoretically grounded, there are no clear suggestions for how to implement them in the design of educational technology.

In an attempt to guide actual design, Quintana et al. (2004) have proposed a scaffolding design framework that builds on current proposals of general scaffolding principles (Linn, Davis, & Eylon, 2004; CILT, 2004). This framework is theoretically grounded in: (a) cognitive apprenticeship (Collins, Brown, & Newman, 1989) which specifies how performance of complex tasks can be distributed with others providing assistance, (b) cognitive models of learning by doing (Anderson, 1983; VanLehn, 1989) which specify expertise and learner difficulties, and (c) social constructivism (discussed previously). The framework provided by Quintana et al (2004) organizes scaffolding guidelines around three central components of scientific inquiry: sensemaking, process management, and articulation and reflection. The guidelines describe the kinds of support learners need to perform each of those inquiry activities. Explicit scaffolding strategies are then provided for each guideline which provide concrete ways these guidelines could be realized in software design.

There are still no specific prescriptions for how to implement scaffolding. Specific design decisions must be based on context and an analysis of the learner's obstacles. The guidelines and strategies provided by research can guide these decisions. Scaffolding can be incorporated in any kind of educational technology. The strategies available for use, however, are limited by the theory of learning which drives the instructional design. A richer array of scaffolding strategies is available for use in a constructivist learning-environment than in an intelligent tutoring system.

Evaluation. The final phase of any development cycle involves evaluation. In UCD, the evaluation is mostly focused on the usability of the tool. In LCD however, the evaluation must assess how well the educational product (e.g., ITS or learning environment) supports the learner as they perform and learn the target practice. Two very different evaluations are needed to determine the efficacy of the educational product (Salomon, Perkins, & Globerson, 1991).

An "effects of" evaluation provides global and summative information about the educational utility of the product as a whole. Such evaluations focus on changes in learners' understanding after they have used the product. Traditional methods for doing "effects of" evaluations include pre and post testing and controlled studies, where comparisons are made between learning with and without the product. Such evaluation methods allow one to make general conclusions about the effectiveness of the educational product.

An "effects with" evaluation provides local and formative information about how learners interact with various features of the educational product. Such evaluations provide much richer information than "effects of" evaluations and therefore help create a more detailed profile of product use. There are a variety of techniques used to gather this type of "effects of" information but most have an observational aspect. Developers may ask learners to think aloud as they interact with the product or view video of learners in an attempt to understand the conditions leading to impasses and how any provided assistance was used by the learner. Evaluation methods can also focus more directly on specific supports provided by the system to assess their usability and utility to the learner.

Some recommendations for MAVEN-SA training project. In light of this review of instructional design, theories of learning, educational technology, scaffolding techniques, and evaluation, we propose the following directions for phase II of this project.

- Application of a learner-centered design approach. The currently implicit expertise that is built in to the current battlefield visualization tool must be made explicit and accessible to the learner. A careful task analysis will help to determine parts of the target task which are likely to cause the learner difficulty, and thus require support to meet learner needs.
- Design of a scaffold-rich learning environment. A social constructivist approach is the most appropriate for teaching the targeted complex battlefield visualization practices. By embedding the existing tool in a system of supports, learners will participate in a context that reflects the language, tools, culture and representations of the practice.
- Performing "effects of" and "effects with" evaluations. Although the client of this training development project will be most interested in the "effects of" evaluation, the "effects with" evaluation will be invaluable during the design process and for research purposes.

Review of Military Applications of Digital Training Literature

The Defense Science Board report on Training Superiority and Training Surprise (DSB, 2001) and the subsequent report on Training for Future Conflict (DSB, 2003) both identify training as an area with great potential if implemented correctly, and a great risk if not addressed more pervasively. As new technologies are developed and fielded as part of DoD-wide transformation, this potential and risk becomes even more pronounced. Scaffolding can be a key enabler for implementing a broad class of military training technologies that is well-supported by the military training literature. Schaab and Moses (2001) note that individualized training can be up to five times more effective than group training. By developing training tools and materials around core, measurable goals, the amount of support needed can be customized to individual learners. They also call for the type of constructivist approach to instruction for which scaffolding was specifically designed. By putting the learner closer to the context in which the material will be used there is a much higher potential for transfer of learning. The scaffolding approach is also fundamental for automatically controlling training conditions (Lickteig, 2000) and can be implemented in a variety of ways to enable individual and team training. As DoD transformation continues, new forms of training that include concepts such as scaffolding will be essential to training all necessary aspects of technology use, beyond traditional military concepts to include both the use of new technology and how to apply it in military operations (e.g. Lynch, 2001).

Visual Display Construction Support for Visualization Training

Visualization is the conversion of collections of strings and numbers (or datasets, as they are often called) into images that allow viewers to perform visual exploration and analysis and the viewer's interpretation of these images. Visualization begins with the construction of a data-feature mapping that converts the raw data into images that are presented to the viewer. An effective visualization chooses a data mapping feature to support the exploration and analysis tasks the viewer wants to perform. Multidimensional techniques must address both the size and the dimensionality of a dataset. The challenge is to design visualizations that represent even some of this information simultaneously in a single display, without overwhelming a viewer's ability to make sense of the resulting images. This is partly a challenge for the designers of visualization systems and partly a challenge for their users, the practitioners in the field, who have the final responsibility for configuring their visualization systems to develop meaningful mappings. Unfortunately, mapping techniques are not always simple to understand or apply. Practitioners are now faced with visualization tools that offer an extensive set of options to present information, but no assistance on how to harness or control the use of these options to produce an effective result. As has been discussed previously in this report, the development of these mappings is a skill that requires training.

In previous work (Healey, St. Amant, and Elhaddad, 1999), we have designed a *visualization assistant*, a combination of perceptual guidelines and an intelligent search engine designed to identify the data-feature mappings that are most appropriate for a particular dataset and associated analysis tasks. Our visualization assistant, called ViA, is specifically engineered to satisfy a number of important goals:

- ***visually effective:*** each mapping suggested by ViA should produce displays that allow a viewer to rapidly, accurately, and effectively conduct their exploration and analysis,
- ***domain independent:*** ViA should not be constrained to a particular type of environment, rather, it should generalize to a wide range of real-world applications including military operations planning and command and control,
- ***allow context:*** ViA should allow a viewer to add domain-specific context as necessary to a mapping, and
- ***computationally efficient:*** ViA should not perform an exhaustive search of all possible mappings, rather, it should concentrate on mappings that are most likely to produce effective visualizations.

The result is a semi-automated system that can identify perceptually salient visualizations for a broad collection of application environments. Viewers can describe their requirements, ask ViA to locate candidate mappings, and refine those mappings as needed to produce a small collection of mappings that are best suited to a given dataset and analysis task.

ViA was designed to enable users to develop visualization data mappings for use in solving operational analysis problems. The implication, however, is that ViA is only able to support visualization users that are currently equipped with a tool that contains ViA. The same scientific and design principles that enable ViA in this mode, however, can be productively turned to visualization training, better equipping visualization users regardless of the visualization system with which the are currently manipulating.

Mixed-initiative search. The algorithms within ViA are based on recent advances in interactive and mixed-initiative search (Burnstein & McDermott 1996). Some forms of planning (Weld 1994) bear a strong resemblance to the construction of good visualizations, in that both processes rely on the concepts of "flaws" in a partially complete structure or process, total and partial ordering of elements, and incremental construction and evaluation. Mixed-initiative algorithms have been modified and extended to support external advice during search. This allows the evaluation engines to guide the search towards perceptually optimal data-feature mappings. It also allows viewers to direct the selection of data mappings with respect to context in a dataset, or to include features that they deem important. It will also allow ViA to introspect over its incremental construction plan and describe individual decisions to the trainee. It will also, in principle, be possible to feed student constructed data mappings to the same evaluation engine for review and critique.

The evaluation engines analyze each mapping based on the dataset's properties and a viewer's analysis needs. ViA begins by asking viewers a set of domain-independent questions about the dataset. The particular properties we identified come from previous work on automated visualization (e.g., in Bergman, Rogowitz, & Treinish, 1995, Gallop, 1994) and from the psychophysical experiments used to study the perceptual properties of color and texture. Specifically, the viewer must define:

- ***importance ordering:*** the relative importance of each attribute,
- ***task:*** the analysis task(s), if any, to be performed on each attribute,
- ***spatial frequency:*** the spatial frequency of each attribute, and
- ***domain type:*** whether an attribute's domain is continuous or discrete.

Although ViA will try to infer some of the dataset's properties (e.g., spatial frequency and domain type), viewers can override any of these decisions.

Viewer interaction. The mixed-initiative nature of the search allows ViA to query viewers about choices that they are best equipped to answer. For example, discretizing a continuous attribute can allow for improved mapping (this is particularly true in situations where viewers want to search for or estimate the relative number of a specific value of an attribute). If ViA identifies this opportunity, it may ask the viewer: "Will you allow me to discretize this attribute into equal-width ranges?" Other situations can cause ViA to ask to rearranging the relative importance of closely ordered attributes, or to ignore certain analysis tasks for low-importance attributes. This is not only a chance for ViA to generate better candidate mappings; it also allows viewers to refocus their priorities based on results-to-date, and to examine in more detail specific aspects of the application environment. Indeed, certain initial choices for the dataset properties and analysis tasks may receive little consideration until ViA asks for particular changes or modifications. Since a viewer's time and attention are scare resources, ViA restricts its queries to only those situations where obvious improvements may result. ViA caches viewer responses to ensure that the same (or similar) questions are not asked again.

ViA as a training component. As described, ViA can serve a number of roles in training basic visualization skills including (a) providing optimal answers to act as references, (b) providing explanation of the process used to derive these optimal answers, (c) evaluating and critiquing student incremental data mapping decisions and final data maps. In a scaffolded training environment such as proposed by this report, these features can be used in isolation or combination and faded as trainees gain mastery over specific skills.

Review of Mixed-Initiative Interaction Support for Computer Based Training

Mixed initiative has been defined in a number of ways to suit the goals of different research projects including significant application in computer based training. In general, mixed-initiative systems attempt to solve problems in collaboration with users, rather than acting rigidly as a tool that only processes direct commands or an agent with complete autonomy in pursuit of the goals it is supplied. The concept of mixed initiative is derived from work in natural language processing, in particular discourse modeling. In natural conversation, participants ask and answer questions, supply information without necessarily being prompted, opportunistically interject different kinds of information as needed, and in general interact with each other as peers in their exchange. Mixed-initiative systems can be built around different organizing principles, but all mixed-initiative systems must generally address the following issues:

- How responsibility is divided between the user and the system for tasks that need to be performed
- Under which conditions initiative (in many cases control) shifts between the user and the system
- How a shared representation, which may be implicit on the human side, can be shared between the user and the system
- How communication proceeds via different possible genres of interaction

Over the past decade or so, two different genres of interaction have dominated research on mixed initiative: conversational interaction and direct manipulation interaction. These genres are not necessarily disjoint; they can be combined in a variety of ways in multimodal and multimedia systems to meet the requirements of specific domains and audiences.

Conversational interfaces interact with users either via speech or typed input; they mimic natural interaction between human conversants. In conversational interfaces, turn taking is common, with shifts in initiative corresponding to which participant is speaking or contributing to the conversation at a given point. Researchers generally distinguish between dialog initiative and problem-solving initiative. For example, if one participant is asking questions in order to solve a problem for which the second participant has critical knowledge, then the second participant, in guiding the first, maintains problem-solving initiative, while first participant often must take dialog initiative by prompting for answers.

In *direct manipulation interfaces*, users see and manipulate information through the medium of a virtual graphical environment, such as the Windows desktop. Interaction with a direct manipulation interface is typically constrained such that the only information that the system provides the user is that which is explicitly requested by the user (neglecting warnings and alerts.) The drawback to such interaction is that if the system has information or capabilities of which the user is unaware, especially in time-sensitive scenarios, it may not come to light. Mixed-initiative extensions to direct manipulation interfaces address this problem by allowing the system, under some circumstances, to autonomously volunteer information or actions that it can perform. One advantage of this type of mixed-initiative interface is that such interfaces can often be constrained to fit into existing task environments in which conversational interaction would be impractical.

A number of different techniques have been developed to enable systems to interact with users in mixed-initiative fashion, across both genres described above. As with interaction genres, these techniques may be combined.

- ***Probabilistic and decision theoretic approaches:*** In early work, Biswas and Yu (1989) took an approach to designing mixed initiative systems that relied on the Dempster-Shafer evidence combination scheme, implemented in the form of a rule network. More recently, Horvitz and colleagues (Horvitz, Breese, Heckerman, Hovel, and Rommelse, 2003) have approached the problem of mixed initiative using Bayesian reasoning concepts. By determining probability distributions over possible user goals, a system is able to reason about actions that it can take to facilitate goal achievement. Horvitz (1999) has formalized this work in the form of interface design principles for mixed-initiative systems.
- ***Planning approaches:*** Some of the best-known results in mixed initiative come from the planning literature. The TRAINS and TRIPS (The Rochester Interactive Planning System) systems (Ferguson, Allen, Miller, Ringger, 1996, Sikorski, Allen, 1996) interact with users through a multimedia interface (graphics, speech, text, etc.) to solve resource allocation problems collaboratively. The key idea that such systems apply is that human activity in complex domains is often amenable to partial solution by planning techniques. A system that can offer to elaborate partial plans supplied by users, and possibly to recognize users' goals based on their actions, can significantly improve overall performance.
- ***Discourse-based approaches:*** Mixed-initiative conversational systems draw on a long history of research on the properties of discourse, which provides a strong theoretical framework for what actions a system might take in service of shared discourse goals. The most mature research in this area is Collagen (Lesh, Marks, Rich, Sidner, 2004). By making inferences about the user's activities, Collagen can ask fewer questions; by maintaining a model of user activity, Collagen can ask questions at appropriate times and in the correct informational context.

Dating back to the earliest mixed-initiative systems research, a primary application area for mixed-initiative systems has been computer based training. Carbonell's SCHOLAR system (Carbonell, 1971), for example maintained a dialog with students through their instruction both providing instructional feedback and allowing the student to ask questions. This approach continues to be a basis for training systems, including intelligent tutoring system research (Anderson, Corbett, Koedinger, & Pelletier, 1995) and user-adaptive learning environments (Meier, Melis, Pollet 2003). Mixed-interaction offers education systems training mechanisms that can both personalize training and allow a variety of student-system dialogs including feedback, questions, and self-explanations.

Summary of Phase I Results

Our effort to develop concrete training goals, methods, and approaches for battlefield visualization achieved the following results:

1. ***A working scenario was defined on which to determine project feasibility. This scenario centered on a company level MOUT cordon and search mission.*** With SME support, we developed a working scenario that defined a tactical environment and a series of important mission considerations for the commander. These considerations were expanded to highlight information required for maintaining SA and battlefield awareness.

2. ***A comprehensive GDTA of a company commander's information needs to maintain situation awareness during a MOUT Cordon and search mission.*** We used an open interview process with a military SME to systematically expand on the information requirements identified during the scenario definition period. The GDTA that resulted begins with seven high-level goal areas ranging such "Protect the force / Avoid Casualties" and "Control Civilian Population." These high-level goals are expanded into almost one hundred individual goals, two hundred specific information requirements and correlated sets of information types.

3. ***Review and synthesis of appropriate literatures.*** We developed a description of basic visualization skills, built on current research in perceptual and cognitive psychology, that underlie the connection of internal cognitive schema and external visual representations. We mapped this set of skills to the requirements of situation awareness and battlespace visualization. We describe a number of historic approaches to educational pedagogy that have guided the development of training technology and propose specific approaches to digital training of the basic visualization skills.

4. ***Developed a basic visualization capability for perceptual display optimization for MOUT environments.*** While the visualization prototype does not, in its Phase I state, include appropriate tools and content for training, it provides a basis visualization capacity and highlights the kind of external battlefield visualizations that a trainee might develop.

5. ***Develop concrete phase II training goals and training tool/environment approaches.*** We developed and described four different training/tool concepts including: an individual trainee basic skills part-task trainer and training module, an individual trainee whole-task visualization tool and training module, an individual trainee simulation based 4D visualization tool, and a instructor MOUT visualization training presentation tool.

Phase II System Design

The purpose of this section is to provide a high level overview of the design of the software infrastructure that will be built for Phase II of the MAVEN project. During the MAVEN Phase I we developed four options for Phase II research and development. The first three we framed loosely around SA levels and focused on developing a training module and interactive training tool to be used by individual trainees. The fourth option focused on developing a training module and presentation tool to be used by a classroom instructor. Following are brief descriptions of the tool concepts. Each concept put an emphasis on different approaches to use educational technology to improve battlespace visualization training. While we felt each option has merit and would provide benefit to the Army, we decided to focus on Option A "Basic Visualization Skills."

Option A. Basic Visualization Skills (SA-1)

This option focuses on developing part-task visualization training lessons for individual trainees that develop basic SA-1-relevant skills; such as representation reference mapping, pattern detection, scene change detection, and other skills necessary for situational assessment and perception of relevant data. This approach would use the underlying visualization system to provide basic visualization support and as the basis for a tutorial dialog with the trainee. This dialog would interactively explain visualization rational, suggesting visualization configurations, and providing problem-solving hints. This interaction would be structured as an educational scaffold, allowing specific supports to be removed as trainee skill and confidence increases. The goal of this scaffolded approach is to enable the trainee to develop transferable skills that will serve the trainee regardless of the visual media with which they are working.

Training focus. This option stresses individual student interaction with the training tool in the context of a larger military training course such as the Intelligence Preparation of the Battlefield lesson from Army Training Circular TC 7-98-1 "Stability and Support Operations Training Support Package" (Department of the Army, 1998). During this interaction, the student would be presented with a series of training exercises that would develop basic external-artifact based visualization skills, including:

- Visual Image Comprehension: Develop basic rules of visual language by presentation and examination of standard military visual representations (such as Course of Action map) focusing on what is expressible by and interpretable from these representations and visual representations in general. For example, standard MIL-SPEC-2525b C2 symbology (U.S. Department of Defense, 1999) can represent locations of enemy units, including a range of unit characteristics, but cannot (by itself) represent the degree of certainty in the assessment of unit type or time since last verification of unit position.
- Visual Image Development: Develop basic rules of visual image construction focusing on translating a specific information or communication need into selection of appropriate visualization representations or projections based on the characteristics of their visual language. For example, choosing between 2D and 3D images and choosing appropriate display layers (built features, terrain features) and layer configurations requires understanding what which representation feature are required to articulate a particular concept or intent. For example, Intelligence Preparation of the Battlefield and CCIR recognition have different requirements for representing sensor capabilities and coverage.
- Pattern and Situation Identification: Develop basic skills in techniques selection, alignment, and annotation to create frames of reference across multiple images or data sets relative to a particular area of interest. For example, using a time series of satellite images to identify newly constructed barricades, sniper positions, or possible Improvised Explosive Device (IED) locations.

Research focus. Expansion of VIA mixed-initiative to model, suggest, and/or criticize student visualization manipulations.

Display mockup. The following training system screen interface mockup (see Figure 19) highlights Intelligence Preparation for the Battlefield for Countersniper Measures training and suggests what the basic skills trainer tool might look like.

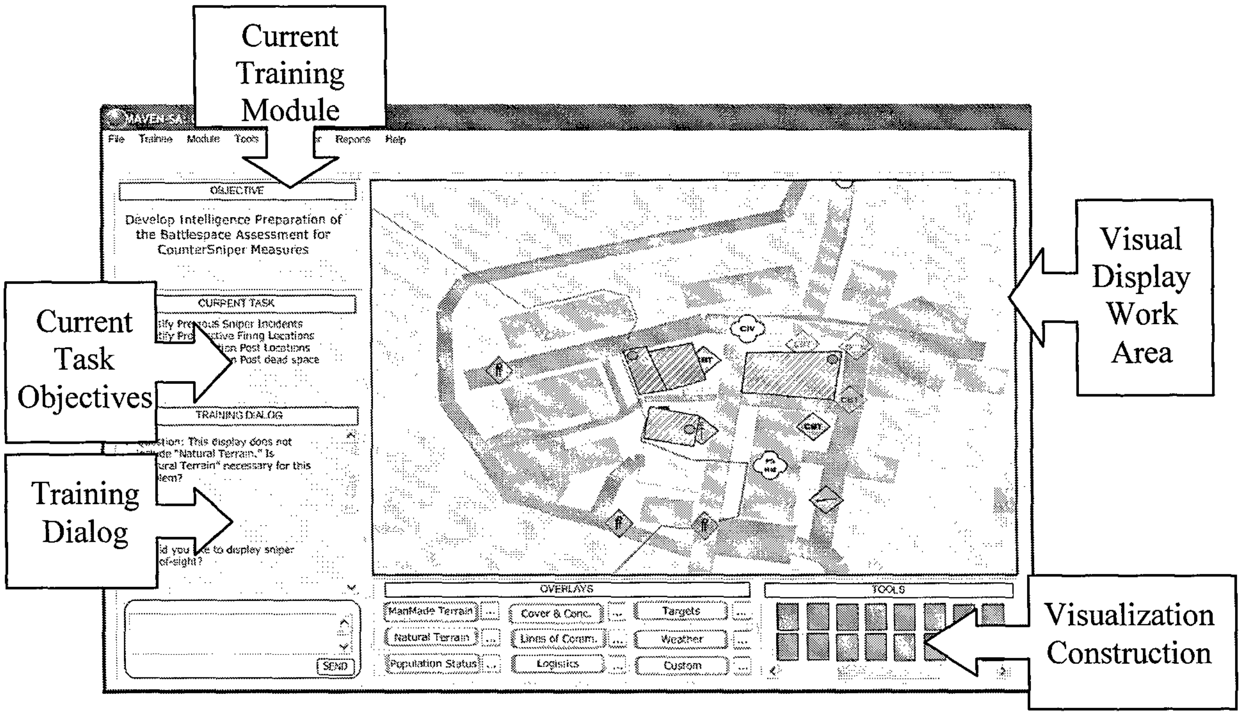

Figure 19. Basic Skills Trainer Mockup, showing training dialog, display control and current tasks.

The primary screen modules shown include displays for the current training module and current task progress, the mixed-initiative training dialog, the visualization construction panel, and the visual display work area. This approach balances the text based hint and query capability of the training dialog with the direct display manipulation of the visualization construction kit.

Option B. Comprehensive Visualization Skills (SA-2)

This option focuses on developing training for Situation Awareness Level-2 situational comprehension skills. The technical focus would be on developing a scene creation tool and improved visualizations for MOUT environments. Where option A would include developing individual lessons and encoding them within the tool, Option B would depend on the trainer to develop training problems that a trainee would use the tool to help solve. This option also focuses on scenario level training as opposed to part-task training. For training we would emphasize developing skills necessary to build internal schema necessary to conceptualize the situation, which would then form the basis for situation awareness in an operational setting.

Training focus. This option also stresses individual student interaction with the training tool. During this interaction, the student would be presented with a series of training exercises that would develop advanced battlefield visualization skills. These skills would focus on using visual representation to support specific training house objectives, such as using visualization to:

- Improve sensor placement or usage for Intelligence Preparation of the Battlefield
- Improve METT-TC awareness for COA development

Research focus. Expansion of VIA visualization optimization capabilities to handle wider range of Army visual representations and representation requirements.

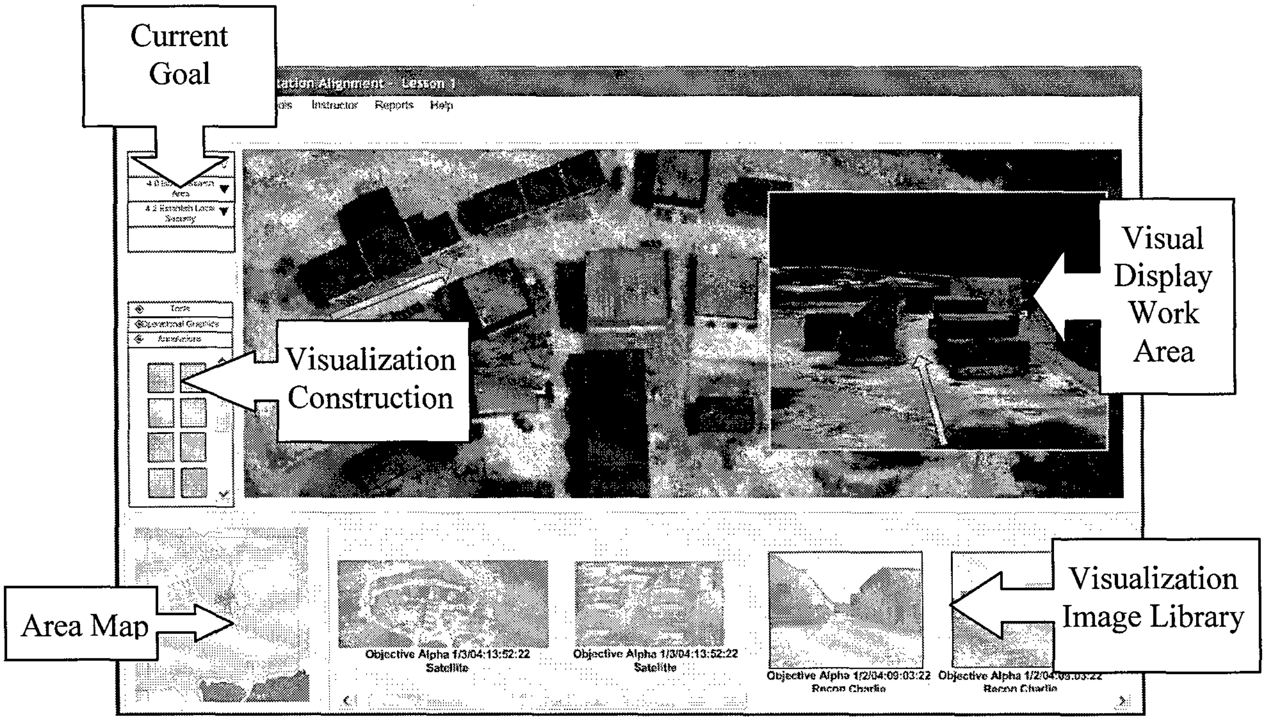

Figure 20. Situation awareness trainer mockup, highlighting visual image integration and alignment.

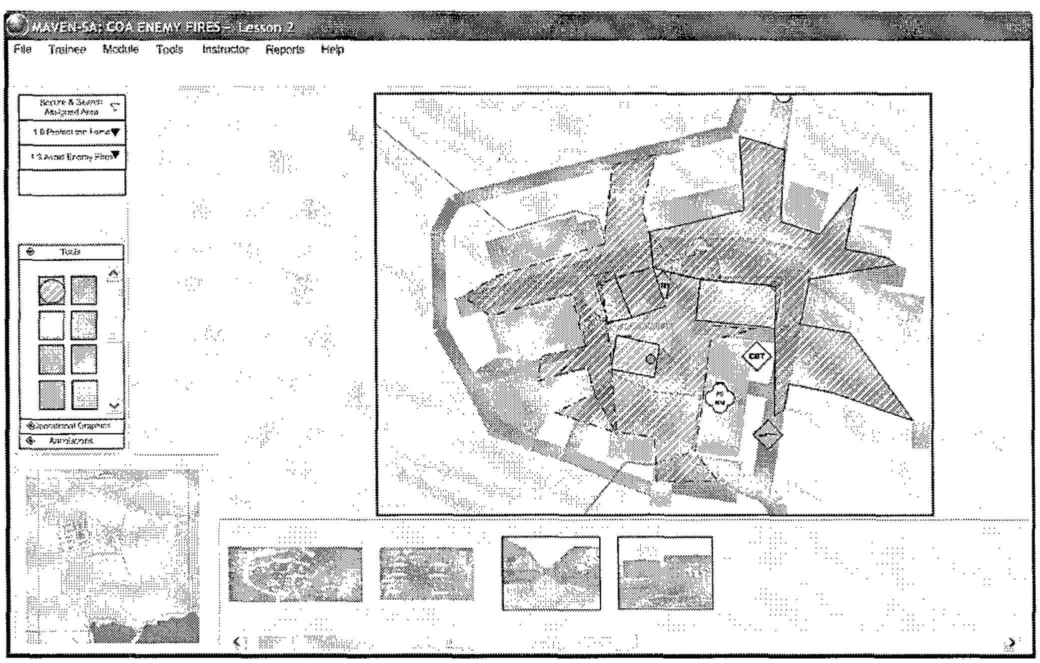

Figure 21. Situation awareness trainer mockup, highlighting sniper line of sight development.

The primary screen modules shown include displays for the primary visualization display area, visual image library and area map, as well as a visualization construction tools panel, and a current goal selection panel.

Option C. Projective Visualization Skills (SA-3)

This option focuses on developing skills necessary for SA-3, situational projection. This option was not explored in depth and was described as a known out-of-scope option that could build on A and/or B at a later time. The technical focus for this option would be to link to SAF-level simulation environments that would allow full scenarios to be played out with adversaries, and under more realistic conditions. Other possible features would include a full trainer GUI for composing, running, and evaluating training scenarios, and intelligent tutoring agents to assist the user in understanding the training objectives.

Option D. Trainer Development and Teaching Tool

This option focuses on developing teaching aids that could be used by trainers to improve, simplify, and otherwise assist in their development and presentation of MOUT visualization training materials. It would include aspects of each of the other three options including support for developing individual scenes that could be displayed individually or chained together. This tool is analogous to Microsoft PowerPoint ® for MOUT visualization training and would make use of an underlying visualization modeling system as Option B, but would not require a Trainee interface. Unlike a generic 3-D modeling system, it would know about MOUT domain-specific objects, relationships, etc., and would include a set of heuristics for displaying visual features of interest.

Training focus. This option stresses trainer preparation and presentation of course material. This tool would allow a course designer to prepare a set of MOUT images based off either satellite images or map data, annotate these images with text, symbols, or specific relationships markers or color/feature encodings. The course instructor would then be able to display and manipulate these images in real-time. Envisioned manipulations include 2D or 3D zooming and panning to provide image fly-over or fly-through, limited animation to highlight regions of interest, real-time annotation. We believe that there is a lot of merit in option D in that it considers better how the tool might be incorporated within the Officers Advanced Course training regimen.

Research focus. Design of visualization/scenario specification and display approach that will support schoolhouse visualization training.

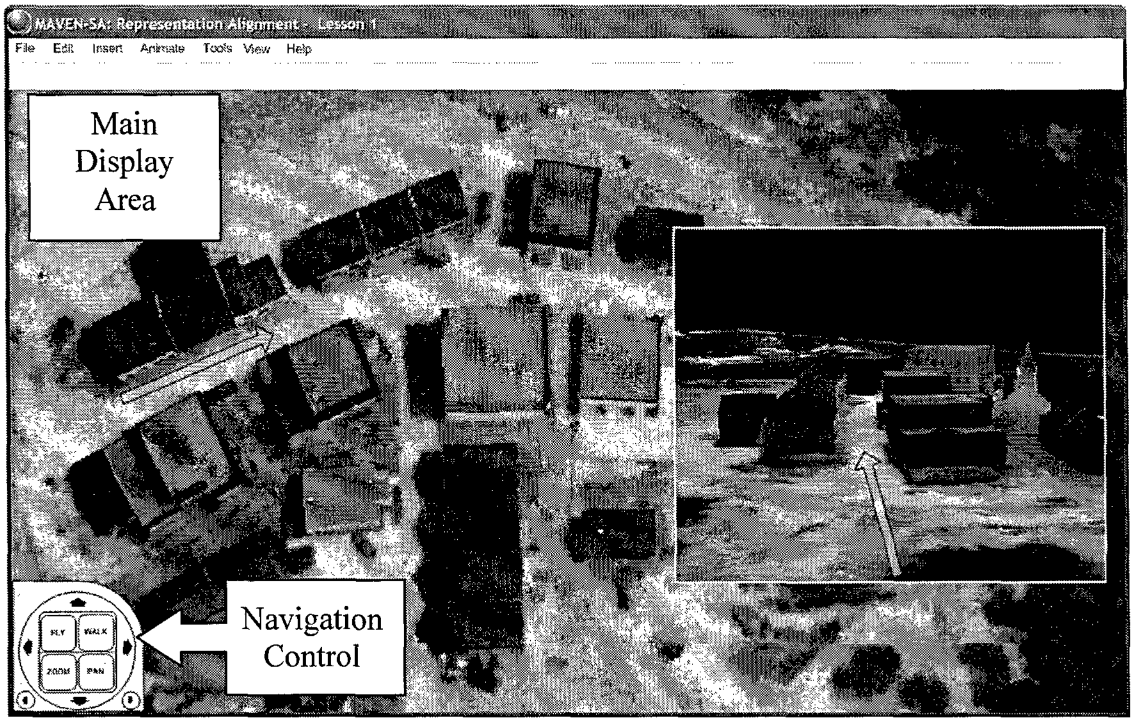

Figure 22. Classroom presentation tool.

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