SCENARIOS AS A TOOL FOR COLLABORATIVE ENVISIONING

A Thesis

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By

Joshua Aaron Schoenwald, B.S.

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Master's Examination Committee:

Dr. David Woods, Advisor

Dr. James Tittle

Approved by

Advisor

Department of Industrial, Welding,

and Systems Engineering

ABSTRACT

This research describes the use of a collaborative envisioning tool to combine the goals of disparate communities concerning the role of new sensor technologies being deployed in Military Operations in Urban Terrain (MOUT). To do this, I work at the intersection of Cognitive Engineering with the sensor development and military operations communities. Through the use of scenario-based design and the Topic Landscape tool, generic patterns provide seeds that help envision realistic futures of MOUT which are expressed in a narrative. These patterns provide insight on two levels: On one level they describe complexities inherent to all cognitive work, while on another level they provide insight about what makes MOUT difficult. The Topic Landscape is a collaborative tool that organizes information from a Cognitive Task Analysis of MOUT in many forms (text, graphics, video, etc.) from many contributors.

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VITA

March 16, 1978 ....Born, Los Angeles, CA

2000..B.S. Cognitive Science, University of California, San Diego

2000-2001 ....User Interface Designer, LiveWorld, Inc.

2002...Design Consultant, California State University, Channel Islands

2002-2005 ....Graduate Research Assistant, The Ohio State University

PUBLICATIONS

Research Publications

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CHAPTER 1

INTRODUCTION

Figure 1.1: Soldier amongst rubble in WWII Germany, 1944.

Increasingly, the United States Military has been conducting operations in urban environments. This radically different battlefield introduces new complexities which demand the adaptation of units on the ground as well as higher echelons. Understanding the difficulties of Military Operations on Urban Terrain (MOUT) and using new technology to support these operations is particularly important in a time of asymmetric international conflicts. New technologies are being developed to allow the military to conduct urban operations more safely and effectively. One such technology is that of unattended ground sensors (UGS), which aim to be smaller, cheaper and more versatile for use in the urban environment. Part of this development process includes matching the capabilities of the technology to the real needs and constraints of MOUT. The development community is under real pressure to provide the problem holders (military personnel) new fieldable systems to improve performance. The technologists (sensor technology researchers) are advancing the capabilities of UGS: smaller, lighter, more robust sensors; multi-modal sensor packets that incorporate photosensors, acoustic sensors, magnetometers and Passive Infrared (PIR) motion sensors; ad-hoc networks of many hundreds of nodes; and new processing to detect more complex patterns in human activity individually and as a network of sensors (Taylor, et al. 2004).

In this project, we use Cognitive Engineering techniques to support collaboration across diverse development groups to facilitate design envisioning. We use cognitive task analyses to understand the real challenges and constraints facing practitioners which points us in new directions for promising designs. The specific context is how new sensor technology can support more effective MOUT operations. The techniques are a form of scenario-based design methods and use a shared multimedia visualization concept called the Topic Landscape to support collaborative envisioning. Our use of scenarios as tools for envisioning allows us to predict the influence of new sensor technologies based on our understanding of the complexities of MOUT. The Topic Landscape tool acts as a resource that's always available for collecting this information and sharing it with other contributors. Through our methods we are able to understand how to re-imagine elements of the MOUT domain to incorporate new sensor technologies.

CHAPTER 2

THE ART OF ENVISIONING

Imagining a future state of the world is critical component of the design process. In order to create or modify something to impact some environment, you must be able to project the implications of your design into that future world. This process of envisioning enables you a glimpse into the crystal ball that represents a design which will be successful or doomed to failure or mediocrity.

The envisioning process requires that you possess a thorough understanding of the domain in question. This requires close contact with practitioners in their natural environment. As a designer there is difficulty in obtaining this understanding because it requires a delicate balance of perspectives. Practitioners in a field are heavily biased; their perspective as system developers or experts clouds their ability to critically evaluate the process and view it with the eye of an outsider. When studying a system, becoming an actual practitioner is advantageous for leaning about the environment, but it runs the risk of shifting an objective designer's perspective to that of an insider. To design, one must therefore temper a thorough understanding with the ability to step back and view the situation through the eyes of an outside observer. Not having an understanding of the domain leads you down the garden path of designing what appears to be useful based on cursory and arbitrary assumptions about how the system really works.

Part of the difficulty in envisioning new futures for MOUT lies in its adversarial nature. All environments are dynamic. This means they require continuing design adaptations as environments evolve over time in response to changing patterns of behavior and various external forces. But in the MOUT environment, as with any military or adversarial environment, other forces are attempting to undermine your efforts in a very direct and destructive manner. This means that not only must you understand the restraints and complexities of how the environment relates to you; you must also take into account how your adversary is already adapting to you and attempting to gain an advantage as quickly as possible. This extra burden makes envisioning in adversarial environments considerably more difficult, but also more critical.

Cognitive Task Analyses (CTA) are the key to gaining this thorough knowledge of the domain without assuming the cognitive constraints of an insider. Effective CTA provide you with a breakdown of the things that make work difficult in that domain, but also provide you with clues to know what's important when considering design changes. What are the workarounds? How have people adapted to the situation? What system features are rarely used? Which ones cause the most angst and frustration? Answering these and similar questions will lead you to implications that point to areas where innovation and design changes could bring about improvements in the world. In order to create design solutions that help instead of hobble practitioners (Woods, 2002), you must understand the classes of difficulties and cognitive challenges. These challenges should point to specific solutions which can be effectively implemented through the use of new technology.

In addition to understanding the domain, one must also know enough about the technology in question to appreciate how it can be implemented to solve problems identified by the CTA. This is another reason envisioning requires maintaining the outside perspective of a Cognitive Engineer; one who is familiar with, yet exterior to those working directly with either the technology or in the domain.

Envisioning necessitates the ability to tell a story about the future state of the environment. The story must be plausible as well as practical. A practical story is one that has true face validity to real practitioners and technologists. It must address them at an intelligent level by using relevant terminology and describing the state of events in a way that demonstrates knowledge of the constraints and challenges that make things difficult. This not only provides a story which is factually accurate, but it lends credibility to outsiders by domain experts. A plausible story is one in which the events themselves represent directions that might seem unlikely but are nonetheless valid possibilities of future situations. This adds further credibility to the outsiders, as practitioners envision how their lives would evolve as a result of the indicated changes proposed through the use of new technology.

CHAPTER 3

SCENARIOS: THE DESIGNER'S CRYSTAL BALL

Multiple storylines can play out in a scenario. Scenarios contain an accurate model of the world showing how behaviors continue to adapt to constraints and goals in the field of practice. These adaptations point to generic problems being manifested locally in the domain, and are crucial to understanding and envisioning future behaviors.

3.1 Typical Uses of Scenarios in Design

Many scenarios suffer from pitfalls that disastrously undermine their value as envisioning tools. One of the most common is the practice of using scenarios as hypothesis confirmations. Scenarios are not meant to be used as verification tools, rather they should be exploratory. The difference is that hypothesis confirmation is a narrowing process, seeking confirmations or detractions from a predisposed course of action. Disproving a hypothesis simply eliminates one possible course of action, it does not inherently prove an alternative course of action. Scenarios that function in this manner will suffer from un-obstacles or pitfalls which purport to rigorously test the product but are merely exploitations of problems to which solutions have already been designed or considered.

An example of this was observed through work our lab did with the National Aeronautics and Space Administration (NASA). Their development of an architecture for supporting astronauts consisted of an integrated computer system to monitor vital processes like air supply or water purification. When a problem occurs, the system relies on a 'prime' engineer who is the first responder, then a backup or second responder, and then a third responded if necessary. NASA put together a scenario to demonstrate the use of this system in a simulated environment.

The scenario depicted the prime engineer leaving his desk for a meeting and forgetting his pager. When a problem occurs, he is notified by the pager and via computer message. When there is no response, the system contacts the backup engineer who receives the message and responds to the problem. In attempting to show the robustness of their system, NASA created un-obstacles that show off the automation but don't really test the system. The system designers at NASA thought to include a redundancy if the prime engineer is unable to respond, however this does not represent a true test of the system because this problem had already been solved through design. In essence, instead of showing how the system reacted to a failure or problem, they demonstrated a feature designed to work in a certain situation.

Our work with this scenario began with a process trace of the major characters. For us this became the 3 engineers and a separate character called 'automation' which represents the programmed actions of the automated system. In this process trace (See Appendix G) we divided events into cues, mindsets and actions to gain a better understanding of the state of mind during each phase of the scenario. This provided leverage points to explore possible complications that could assert themselves in different ways on different members of the team at various times. From these leverage points we created a new scenario which took advantage of the fundamental types of problems that would be encountered by any agent in a system of this type. It's important to note here that these difficulties are not related specifically to human agents or mechanical ones; they represent problems in the domain that must be solved at the core by any type of agent or distributed team of agents operating in the environment.

Scenarios are often derived from use cases which describe specific paths through the system in pursuit of a number of goals (Carroll and Rosson, 1992). While use cases are valuable for exploring functionality given a set of goals, they are not designed to evaluate the adequacy or utility of those goals, or more importantly how those goals are changing with events in the world. Assuming that practitioners' goals are either static or well-defined represents a simplification that will produce brittle designs. Additionally, trying to encapsulate an exhaustive list of possible outcomes is a never-ending task that is guaranteed to be incomplete and incorrect as the field of practice continues to change and evolve.

Another scenario pitfall is the tendency to be caught up in the domain without abstracting to see the underlying reasons operators in the field adapted in the ways that they have. These cover stories are important, yet far from sufficient in developing effective scenarios. The specific domain or setting in which the scenario takes place gives a sense of realism and enables participation and acceptance from those who are real stakeholders. But the domain is not the level at which adaptations are understood or explained. Simply writing a story about Military

Operations on Urban Terrain does not constitute an effective envisioning tool if all of the problems are represented as solely dependent on the constraints of the domain. Those domain constraints should be thought of as complicating factors of general problems requiring adaptations by the stakeholders. While the particular adaptations and complications might be unique to the MOUT environment, the problems themselves are not rooted there.

3.2 What makes a good scenario?

Scenarios are hypotheses about the future state of events within a system, and as such they represent a model of the environment. Specifically, they represent the model of the system designers. It is therefore important to consider not only the scenario itself but also the model which compels its derivation. These models are a product of the goals, constraints, and technology that drive the designers.

Scenarios convey a hypothesis about an envisioned world (Bødker, Christiansen, 1997), one that utilizes one or more elements that are in the process of being designed. Through the scenarios, these elements are tested to gain a deeper understanding of how they might perform and interact with the environment (and how the environment might react to them). To this end, it is important that scenarios have a high degree of face validity and an accurate model of the environment. But not only must the environment be accurate unto itself, it must represent a realistic (and therefore accurate) environment for the product in question. In essence, testing an airplane's performance using an underwater scenario could be useful -- if airplanes were designed to be used underwater. Scenarios are wrapped around the idea of a narrative, which is an effective means of stimulating effective simulations (Murray, 2005).

An ideal scenario should provide the opportunity for designers to discover the strengths and weaknesses of their model. Models can only be strengthened if we know where they are weak. But the world is not static, and what might represent a weakness in one situation could be a strength in another. Understanding trends toward weaker or stronger models is also something to be tested. Because scenarios represent instantiations of models, we know they will not be wholly accurate, since models are inherently inaccurate to a degree. What's important is that generic patterns of behavior can be identified which underscore the difficulties and help predict the evolution of adaptation to future situations.

In this sense, scenarios have great potential to be used as envisioning tools. By leveraging a thorough understanding of the domain with the classes of constraints, affordances, and functions, we can use scenarios to test the limits of our models which in turn test the designs in a realistic context.

At the lowest level, all scenarios must be 'about' something. The domain describes the type of environment in which events will take place, but it does not deal with the events themselves. A domain can be thought of as a class of behaviors and could be described as being a car manufacturing plant or a military battleground. Definition of the domain is usually driven by the product or service, but that is not always the case, since products can be designed for more than one domain. For domains that are dictated by the product (or other design element), they provide a rich atmosphere of behaviors and actions that define them. It is important to be able to faithfully reproduce these environments with enough authenticity that people who are real stakeholders will embrace them.

While all scenarios must describe some domain and take place in a particular setting, the notion of a scenario and its functions exist separately from any domain. Scenarios embody the representation of generic patterns that describe work in context, however this context is not the core of the scenario. In essence, the scenario is not 'about' anything that is related to the context, or domain. Instead, it's about representing relationships between people and artifacts on a broader level.

This 'deep structure' consists of a set of patterns that apply across multiple settings and possibly multiple domains. Events that occur in a particular setting are merely different instantiations of these generic patterns. These instantiations can take myriad forms and appearances, but at their core they still hark back to those underlying patterns. Understanding these patterns and how they play out means understanding what's really going on in the domain.

Suppose you have 5 apples, and Suzie takes two of them away from you. How many apples do you have left? We know the answer to this problem is 2, but how do we know that? It clearly doesn't involve knowing some inherent property about the nature of apples, or understanding that you and Suzie had pre-arranged a deal to net you 2 apples. It's simple subtraction. Because subtraction is something we understand at a very basic level, we can talk about the word problem in terms of it being a subtraction problem rather than an apple problem. In the same vein, changing the problem from apples to oranges, from Suzie to Carrie, or from 5 apples to 10 apples doesn't change the basic nature of the problem -- it's just another instantiation of a subtraction problem.

Scenarios work much the same way, however the “arithmetic” that underlies the scenario is not always apparent, so we resort to talking about the scenario in terms of the word problem, or setting. While it might seem natural to develop scenarios based solely on their context, it does not facilitate a transfer of knowledge and you become constrained by the dynamics of the domain.

An example of this would be a commander’s decision to advance through vacated buildings when it’s discovered the roads have been set up for an ambush. This represents the larger class of adapting to changing constraints in pursuit of goals. Trying to analyze the decision from a domain-specific viewpoint might lead to the conclusion that streets are never safe because they might be trapped. The larger pattern is how to adapt a plan to meet the intent when impasses are encountered (Shattuck and Woods, 2000). We have successfully used a variant on this story framework—the future incident technique—previously in multi-perspective design envisioning in the context of new air traffic management concepts (Dekker and Woods, 1999).

3.3 Scenarios and Cognitive Engineering

We seek to understand the constraints and pressures acting on people in complex domains. By understanding these relationships, one can design solutions that minimize the cognitive work required to perform various tasks. Cognitive work is not merely a function of the physical (or visible) attributes of some environment, it encompasses intangibles like goals, restrictions, and consequences as well as those of other stakeholders working in the same environment.

Useful scenarios should be about more than just validating initial design hypotheses. To achieve this, methods in Cognitive Engineering are necessary to fully understand the implications of new designs at both a domain-specific and generic (cognitive work) level. The domain level is the most obvious -- encompassing the domain and the physical and directly observable non-physical properties. For example, a new car must be physically able to drive across the ground, and must also be able to produce some minimal amount of horsepower. Designing for the domain is crucial, but not sufficient for success of the overall design. In the car example, ignoring elements like practical use, driver habits, goals, and associated stresses these put on the vehicle, environment, and other drivers is a source of vulnerability and uncertainty.

Scenarios must also address the issue of cognitive work. Understanding cognitive work means understanding the pressures exerted on the people involved to either exacerbate or alleviate mental load levels (Woods, 2002). Because people are the ultimate stakeholders in any domain, this cannot be 'factored out' through the introduction of new technology. Cognitive Engineering recognizes classes of behaviors which underscore cognitive work across domains, and which play out in many forms within those domains.

Cognitive Engineering is concerned with understanding how people cope with the complexities of operational settings like MOUT. Methods like cognitive work or task analysis (Vicente, 1999) help us capture the actual constraints and avoid oversimplifications from the distant desk chairs of system developers (Woods, et al., 2004). Second, Cognitive Engineering is concerned with identifying leverage points about what would be useful in supporting cognitive work in difficult operational settings (Woods, 1998). The major challenge is the task-artifact cycle or the envisioned world problem (Carroll and Rosson, 1992; Woods and Dekker, 2000), where the introduction of new technology transforms the activities and goals that technology was designed to support. In HCI and Cognitive Engineering, researchers have been developing techniques to deal with the challenges of the envisioning process that go beyond mere acceleration of the standard prototype and test of iterative cycles. Many of these techniques are based on using scenarios and storytelling as a means for collaboration across diverse groups engaged in the development process (Carroll, 2000; Woods and Christoffersen, 2002; Feltovich et al., 2004; Roesler et al., 2005).

3.4 Cognitive Engineering and Usability Engineering

Usability Engineering is concerned chiefly with the application of some product in a certain environment. Products are tested for perceived utility in a range of situations designed to approximate expected behavior or use. The focus of usability engineering is on the product, and how it should be changed to produce some desired result. The methods by which these results are achieved come from usability testing and general heuristics about human behavior that often serve as design seeds. Many times these metrics arise from a list of supported features, followed by observations of how the product performs through use by test subjects.

To contrast, Cognitive Engineering seeks to understand the pressures and constraints acting on the stakeholders, and design support for those constraints into the product. Rather than understanding how the product performs in the hands of test subjects, the entire domain must be studied to understand how that product fits and what other pressures could exert themselves and produce potentially unforeseen failures. Usability Engineering is more focused on the experience of people, or users, with a product. The focus for scenario use in Usability Engineering is on the person; how he or she will succeed or fail based on the designs being tested. In this sense, a scenario is a story of some person's experience with a product, rather than a story that focuses on exploring the possibilities of design. Usability Engineering is typically applied when there is a concrete design that needs to be tested. Cognitive Engineering tries to understand what would be beneficial to design based on the conditions of the world.

3.5 The de:cycle

The use of scenarios fits into the larger framework of what it means to design in general. Design has many elements comprising a cycle, since the constantly changing state of the world necessitates continuous design changes and adaptations. One theory on the method of this cycle has been proposed called the design cycle, or de:cycle.

The de:cycle is an integrative model of methods in Cognitive Systems Engineering and Design Innovation. The goal of the de:cycle is to create leverage between traditionally divergent design stages: observing, exploring, and creating. (Roesler, et al., 2005). This integration coordinates the roles of practitioner, asking how they adapt to complexity; innovator, asking how to envision what's useful; and technologist, asking how to bring the anticipated change into the world (Roesler, et al., 2005).

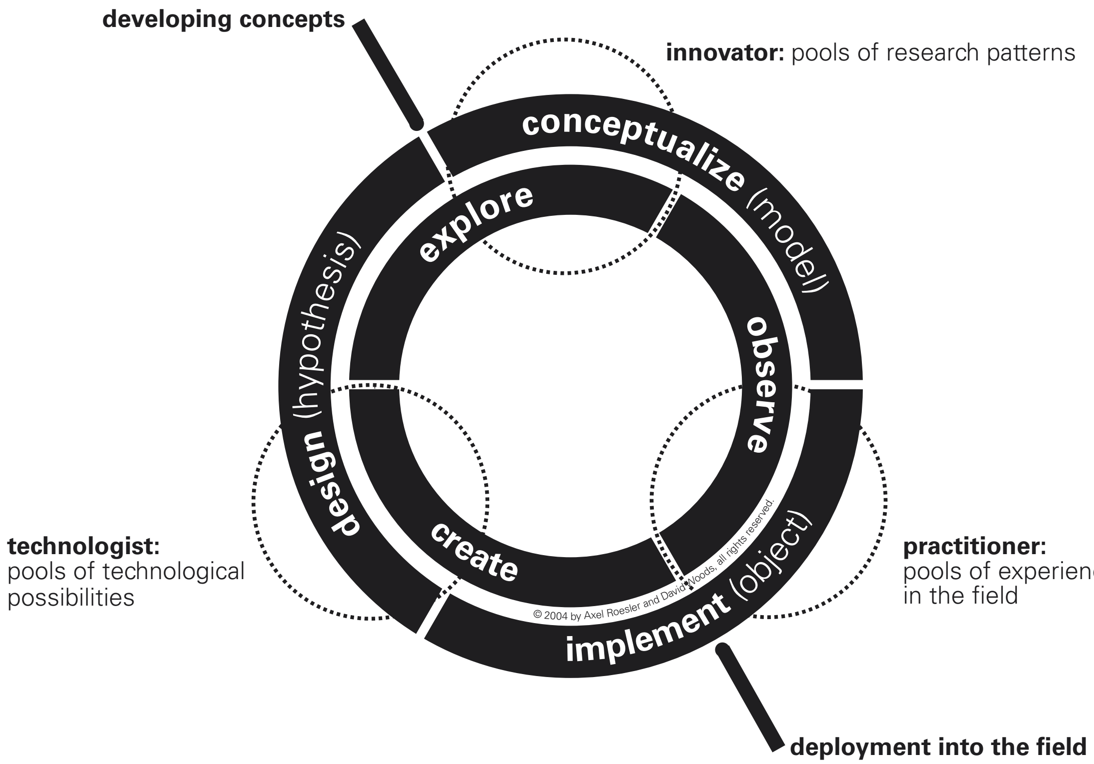

Figure 3.1: The de:cycle. The three roles in design and their respective interests and expertise in a cycle of analysis and synthesis. © Copyright 2004 by Axel Roesler and David Woods.

The design and development of scenarios is part of the de:cycle's conceptualize (or modeling) stage (Roesler et al., 2005). Scenarios are stories about the future which ask the designer to envision a design in a real-world situation. These situations involve domain observations and explorations which support the creation of new designs. Scenario designs come from stories of use, protocols, and data records and are created to produce abstracted patterns, abstract models, and leverage points which continue the exploration of developing concepts.

This kind of scenario development has proven to be an effective means to capture the constraints in the field of practice which dictate behaviors of the practitioners, as mentioned with the project we did with NASA. For that project, we created an animock (Roesler et al., 2001) to help the envisioning process. The animock is a tool that extends the value of the narrative and allows interaction with the scenario along multiple dimensions. The animock works as part of the de:cycle as a tool for envisioning. In the NASA project, the animock allowed us to see the evolving dynamics of the system as they changed in real time. This provided other avenues of exploration which in turn led to further design refinements.

3.6 The animock

An animock is an animated mock-up. The animock concept illustrates a mocked-up design future, animated by a storyline that illustrates use, collaboration, and adaptations in time. The true power of the animock is its ability to show change. Unlike a storyboard, which displays static snapshots of events, the animock shows events in real time, allowing for a much more immersive experience for the practitioner, who can envision other reactions or interesting avenues that would otherwise have been missed. The animock relies on the notion that what's important is the ability to adapt correctly to events, and it's very difficult to show this adaptation with static methods..

As a design tool, it serves as a representation that is open for revision, initiating feedback from practitioners, innovators, and technologists. As a mocked-up, animated world, it forms a stage on which scenarios play out. Animocks are scripted, mocked-up worlds, which are open for revision in two ways: designers and practitioners can modify the storylines that drive the animock. They can also can affect features in the animock world through the design and creation of artifacts and procedures. The animock is a virtual stage on which designs can be imagined - visible to all members of the design team. As tangible representations of a shared design direction, interactions and adaptations can be observed as they play out on the animock stage: design stories link narrative structure with patterns of a research base of use, interaction, and design. Animocks encompass three perspectives which operate as individual dimensions that tell the story from each character's viewpoint of how they move within the scene and across time. These are: Blocking, Pacing, and Point of View.

Blocking refers to the physical movements of people in space. A blocking diagram (Appendix A) might show a map of the entire area and illustrate which actors are moving in which directions as the scenario plays out. The blocking element focuses on how different actors relate to one another in regards to proximity. It helps answer questions like "Where is Actor A when Actor B is at this building," or, "At which point do Actors A and B come face to face?"

Pacing involves the temporal structure of events. A pacing diagram (Appendix B) might show the starting and stopping of various events throughout the scenario. The advantage here is the ability to observe the relative duration of each event and how those relations affect the actors in the scene (using the blocking diagram).

One of the most important elements of the animock is point of view. This typically takes the form of a video in which the events of the scenario play out from the point of view of one or all of the actors. It allows the designer to put himself into the scene and watch events unfold as it would appear to that specific actor. The advantage here is freedom from the designer's omniscient perspective, which tends to obscure difficulties and problem areas. Designers as creators are inherently aware of what's going on in all places of the scenario, but each actor can only be expected to react to what she sees from her point of view. Being able to take this perspective, (or the perspective of any other actor) allows a truly immersive experience.

CHAPTER 4

COGNITIVE TASK ANALYSIS

Figure 4.1: Sgt. squad leader with Task Force Infantry covers his squad as they check a room while clearing a building east of Karbala, Iraq. April 2003. U.S. Army Photo.

To gain an understanding of the MOUT environment we began with critical incident studies of recent urban operations such as the Tet offensive in Hue City, Vietnam 1968; the US experience in Mogadishu on October 3rd, 1993 during the Somalian Civil War; the battles for Grozny, Chechnya in 1995 and 1996; and the 2002 Israeli operation in Jenin, West Bank. This provided us a broad corpus of cases spanning decades which depicts the nature of battle on urban terrain and the typical responses by Western forces to engage in these battles. What's interesting about many of these cases (especially Mogadishu and Grozny) is the extent to which the under-armed, under-manned, and under-coordinated forces won decisive victories over vastly overpowering adversaries. These crushing defeats are a testament to the fact that the urban environment offers numerous surprises and characteristics that give tremendous advantage to those who know the terrain well enough to exploit it. Firepower and manpower are not the determining factors of success in urban combat; it takes a thorough understanding of the evolving dynamics of the battlefield and the adversary which are *opposite* of more conventional battle environments.

To complement these case studies we participated in debriefs of units returning from urban operations in the Balkans, Afghanistan and Iraq, as well as observation of U.S. Military training exercises. The information we gathered corroborates our notion that the urban environment is counterintuitive; for instance it's a bad idea to use tanks in a city because they become easy targets for small groups of foot soldiers with rocket-propelled grenades (RPGs).

We synthesized the available CTA results across these multiple sources (e.g., Innocenti, 2002). Briefly, critical functions needing support in urban operations that may be relevant to new sensor technologies include:

- Orientation to the environment and friendly forces (e.g., the danger of getting lost in urban environments and the need to cross reference landmarks, targets, and locations across units and echelons; the need to coordinate unit boundaries as local terrain makes this difficult and effective asymmetric foes try to exploit them).
- Restrict opponent's mobility (e.g. cutting off routes of escape & approach, sealing off areas).
- Managing civilians in potential conflict areas as there is a complex mix of hostile and civilian populations (e.g., avoid alienating local populace; detecting when civilians are being used by opponents such as bait and trap).

Complicating factors in the urban environment that need to be considered in any human-technology design include:

- Urban terrain changes and is re-designable.
- Different operational tempos in different parts of the cityscape can cause mis-synchronization across units.
- Speed of decisions and situations can change unpredictably across high intensity, low intensity, crowd control, humanitarian situations.
- Varying rules of engagement and opponents who fight your rules of engagement.
- Vertical multi-tiered environment.
- Highly adaptive situations against fast-learning adversaries.

- Operations can be channeled along narrow lanes due to limited fields of view, limited fields of fire, and constricted avenues of approach.
- Risk of friendly fire is high.
- Difficult resource management tasks as urban operations burn through people and other resources rapidly.

In developing our scenario from these CTA results we focused on two main critical functions. The need to restrict opponents' mobility plays out during our checkpoint episode as well as the automated checkpoint exploration (see Chapter 6). The difficulty of managing civilians in potentially hostile areas is a theme that pervades the entire scenario, but is given particular attention in the reconnaissance episode.

In addition to these support requirements, we utilized a number of environmental complications in our scenario as well. The automated checkzone and the evacuation components explore the factors of dynamic and unpredictable tempo as well as the difficulty of highly adaptive and fast learning adversaries. The reconnaissance episode features the vertical, multi-tired environment and limited fields of view and fire.

CHAPTER 5

THE TOPIC LANDSCAPE

The key to envisioning the future of operations given new pressures and new technological possibilities is building ways to integrate the operational, technological and cognitive system perspectives. The means to accomplish this collaborative environment is a shared and evolving story framework within which multiple detailed scenarios can be played out. The story framework creates a future operational setting and story line that can be used to express basic difficulties of urban operations and the opportunities of new technology. The story framework defines a collaborative environment in which different perspectives on a system development can be integrated.

The tool we're using to organize and display this framework is the Topic Landscape. The Topic Landscape organizes a large amount of evolving material based on a basic principle of information design: the navigation mechanisms should be a model of the topic being navigated. It consists of a multi-tiered organization based on simple concepts related to work on visual narratives (Roesler et al.,, 2005). The starting point of the Topic Landscape is a diagnosis that poses a problem and launches an exploration that takes the form of a series of challenges and responses. The advantage of this organization is that it presupposes no linear path, making the Topic Landscape ideal for presenting information as well as developing ideas. Because the Topic Landscape is extendable, it also becomes an ideal tool for collaboration, because different sections can represent different contributors, and this can all be done without disrupting any pre-designed sequencing.

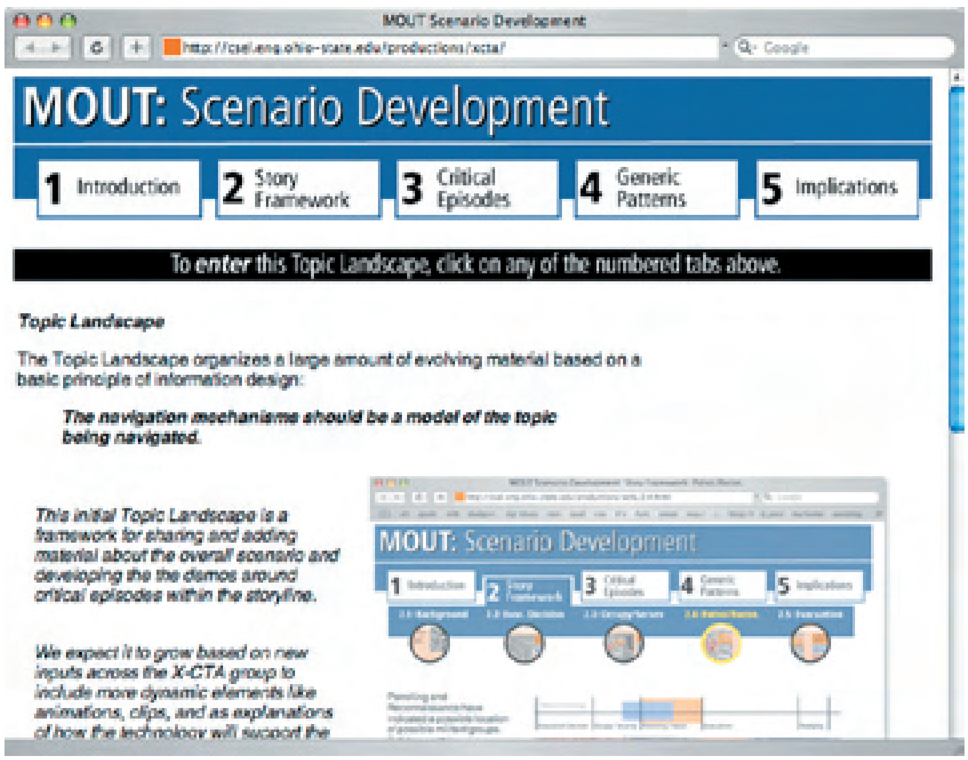

Figure 5.1: The Topic Landscape interface. © Copyright 2005 by Josh Schoenwald and David Woods.

Our Topic Landscape (http://csel.eng.ohio-state.edu/prouctions/xcta) organizes components of a scenario-based exploration to discover what would be useful as design seeds in the MOUT domain. This includes the introduction and overview to the story of operations, the sequence of events, the critical episodes that punctuate the flow, the deeper structure of generic patterns in cognitive demands and coordinated activity built into the domain story, and lastly the implications that emerge from using the scenario to explore how the new technology supports the operations in question.

5.1 Painting the Landscape

The Topic Landscape was created as a website using Adobe Illustrator to design the template. This allowed us to articulate all the aspects of the framework using vector graphics which are scalable and transferable to different formats with ease. Not only that, but it allowed us to create highly complex architectures packaged into incredibly small file sizes. This becomes advantageous as the Topic Landscape can be used on a computer, PDA, or mobile phone and transmitted quickly via wired or wireless connections.

We created the working version of the Topic Landscape as a website. This is the most effective way to facilitate collaboration across disparate groups and to support asynchronous updating and continuous access to materials using various hardware and software configurations. Another distinct advantage of implementing the Topic Landscape as a website is the inherent nonlinearity of its design. Internet hyperlinks offer incredible freedom from the forced sequencing of printed material, and the Topic Landscape is organized such that each person can explore the sections in the order that makes sense based on their unique perspective or interests. As the Topic Landscape grows with contributions from other authors and links to other works, etc; this becomes an even greater benefit. Also, it is easy for collaborators to link to existing websites that contribute to the body of information being developed in the Landscape.

5.2 Introduction

The Topic Landscape we built consists of five sections. The starting point gives an introduction to the MOUT domain and the uses and structure built in to the Topic Landscape. Although the Landscape can be navigated in any order, the content is laid out in 5 sections beginning with an introduction that explains the goal of the Topic Landscape as well as the research methods and background information leading to its development.

The objective in developing a scenario to illustrate a realistic situation in some domain is not merely to write a story about something that could realistically happen: The real value comes when you show an understanding of the domain through abstract (generic) patterns that illustrate the difficulties of cognitive work in any domain.

Our scenario plays out in four main divisions, as follows:

1. Evacuation decision - The decision is made to evacuate a city in a foreign country of all the American civilians.
2. Occupy / Security - The U.S. Embassy serves as the evacuation point and base of operations. Friendly forces assess nearby threats of militant groups.

3. Patrolling and Reconnaissance - U.S. forces actively search threat area for indications of impending conflict.
4. Evacuation - The evacuation effort begins.

The final stage involves the redeployment of soldiers away from the current area of interest. As identified in our CTA, The MOUT domain is particularly interesting because it incorporates a number of unintuitive assumptions. Some of these include:

- It's often difficult to distinguish the civilians from the militants.
- The battlefield has height and depth as well as lateral dimensions.
- The terrain is incredibly re-designable.

These situations and others like them provide challenges to traditional combat models which require those involved to rethink their strategies. They require thinking more broadly and differently about how to design and integrate the sensor capabilities with displays, with the people, in the situation.

In our scenario we provide a context to showcase the potential impact of unmanned ground sensors (UGS) to solve some of the real problems that face troops in urban combat. These remote sensors are described in situations where it seems plausible (given the restrictions and complexities of MOUT) that sensor data could be useful to soldiers. We've identified areas of real problems and concerns that face these soldiers, and make attempts at envisioning the impact the sensors could have on the people and technology in operation.

5.3 Story Framework and Basic Narrative

The second section of the Topic Landscape lays out the framework of the major events that occur within the narrative. This section shows how the scenario will play out at a very high level, which still allows for a lot of customization. Five components are identified which range from the establishing background context to the redeployment of soldiers concluding the narrative. This framework provides a nice overview of how we intend to explore the domain without getting into the specifics of the narrative which will change over time. The story framework is the first attempt to lay down a coherent narrative describing the flow of events. Our goal was to explain the narrative in sufficient detail that coupled with our understanding of the domain, we could then identify places there would be value to both the sensor and operational communities in exploring the narrative in greater detail.

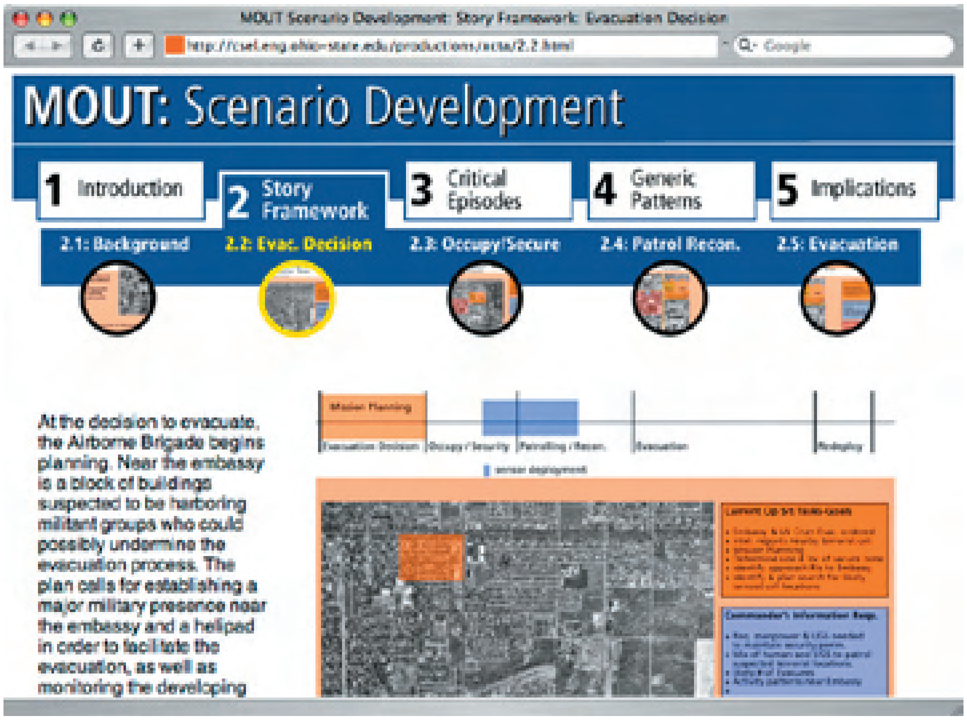

Figure 5.2: Section 2 of the Topic Landscape outlines the story framework comprising the scenario. © Copyright 2005 by Josh Schoenwald and David Woods.

5.3.1 Background

The setting is typical of much of the recent and increasingly common conflicts faced by today's military. The setting is generic enough to allow the events themselves to take any number of paths, but specific enough that it establishes a definite operational context. The following events establish the context upon which the rest of the events overlay.

Events take place in a foreign, semi-hostile country. There is a large city which contains an American Embassy. There are ongoing local government military operations in the country, and the decision has just been made to evacuate approximately 1000 American citizens currently in the city and environs.

A Rapid Reaction Airborne Brigade that has been alerted to conduct the evacuation operation is notified of particularly hostile areas near the embassy. In one area it is known that two militant groups have a long history of fighting. One of the groups is known to be particularly hostile to the U.S, while the other one harbors mostly resentment to the other group but could conceivably pose a threat to the U.S. It is anticipated that most civilians are not hostile towards the U.S, however this could change quickly as a result of events.

5.3.2 Evacuation Decision

The first major event occurs when the decision is made to conduct an evacuation effort. This decision carries planning and logistical implications for the U.S forces currently on the ground as well as the support which is imminent.

At the decision to evacuate, the Airborne Brigade begins planning. Near the embassy is a block of buildings suspected to be harboring militant groups who could possibly undermine the evacuation process. The plan calls for establishing a major military presence near the embassy and a helipad in order to facilitate the evacuation, as well as monitoring the developing situation in the area. Following these operations, it is expected the military presence in this area will be significantly reduced and redeployed.

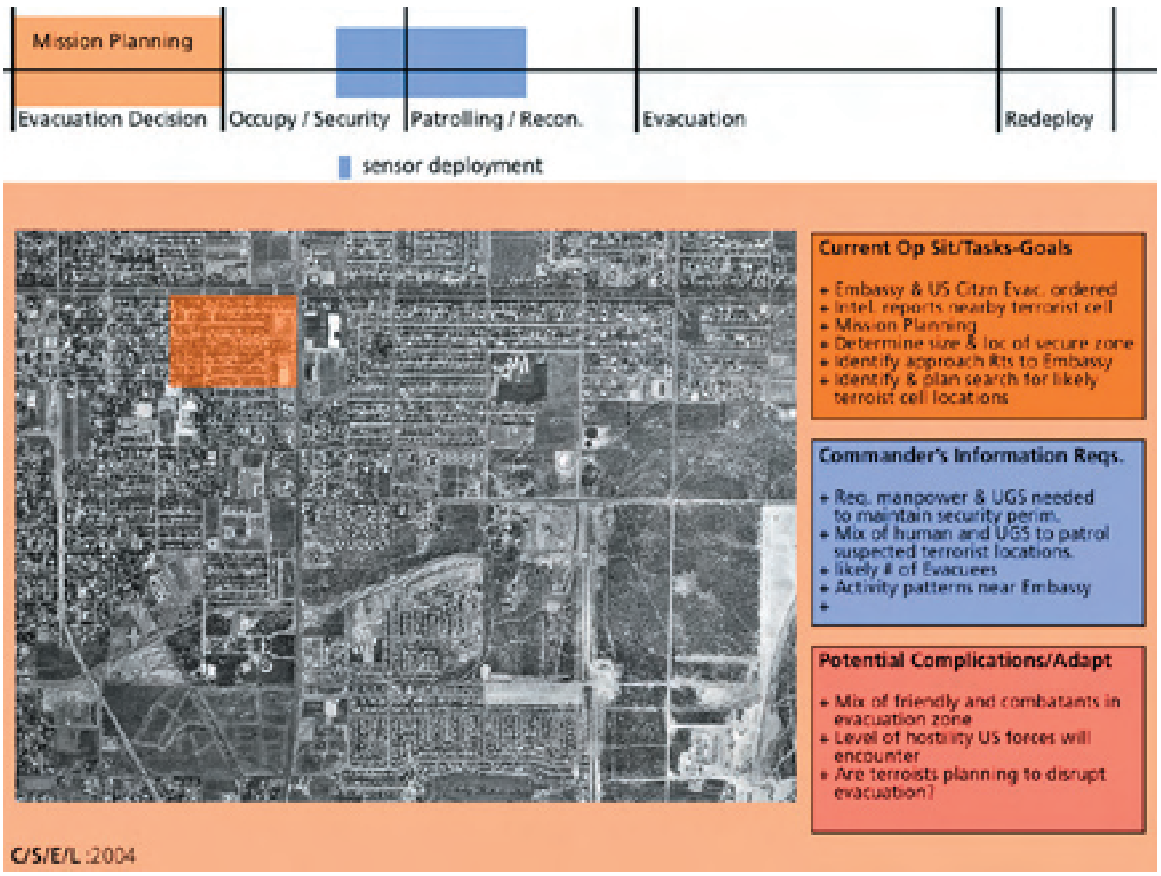

Figure 5.3: This schematic was used early in the development process to map out the basic story arc for the scenario. This stage represents the "evacuation decision" section. At the top is a timeline outlining our first attempt at event sequencing. © Copyright 2005 by Josh Schoenwald and David Woods.

5.3.3 Occupy / Secure

Major occupation and securing of the area mark the next important event in the scenario. A helipad is designated to be used for evacuations by helicopter to the country's main airport. This is the first place where the use of UGS are explicitly defined, however that does not preclude their use (it might encourage it) in other parts of the scenario.

The Embassy is heavily guarded with troops and is serving as the base of operations for work in this area. A sensor network is established around a partial perimeter surrounding the embassy and helipad in areas where there are little or no ground troops. Preparing for the evacuation, reconnaissance missions (squad-sized foot patrols) are being conducted inside the suspected militant area. These patrols will identify typical local behavior and establish checkpoints (CPs) for searches. A Graduated Response Mounted Reaction Force is prepared to reinforce any patrol that encounters hostile activity.

5.3.4 Reconnaissance

After the operation is fully established, patrols are sent out to evaluate intelligence reports of imminent threats in the area. This fourth section in the story framework depicts the sensors being used for tracking and reconnaissance as opposed to intrusion detection. This is a markedly more difficult problem requiring a very different type of analysis and different strategies for deployment and sensor node configuration.

Patrolling and Reconnaissance have indicated a location of possible militant groups. Building searches are conducted and manned intelligence (HUMINT) teams attempt to identify exactly when and where threat planning and preparation is taking place, yet no concrete evidence is found. Because of reported activity in one particular building, it is suspected this place could be used as a safe house. Sensors are placed in the building to help monitor future activity. Meanwhile at the embassy, sensors are placed on avenues of approach to help establish traffic patterns that will help in the evacuation.

5.3.5 Evacuation / Redeployment

The final component of the story framework gets to the evacuation effort itself. Sensor information is aggregated here to thwart would-be saboteurs during the evacuation. At the conclusion of this section, the scenario ends with the redeployment of troops at the conclusion of the evacuation effort.

The evacuation procedures begin as Americans arrive at the embassy. In the suspected hostile area, new information reveals another building that may be a safe house for militants. A platoon is tasked to search the building. The search produces no concrete evidence, and it is determined to place some sensors in this building to monitor the traffic. Because of limited resources, some of the sensors were taken from the first building and reconfigured in the new location.

5.4 Critical Episodes

The third section of the Topic Landscape picks elements from the story framework to be elaborated in detail. The critical episodes are subplots of our general scenario that represent opportunities for collaborators to showcase capabilities of real sensor network implementation. They are not meant to exhaustively define the narrative, rather they represent vignettes of activity all playing out within the larger context. Depending on technology or research needs, these episodes can be reconfigured, reorganized, or edited to highlight different elements of the framework. Our goal was to create believable MOUT narratives. We also included an array of different niches within the subplots that cover the spectrum from problems which are solvable today, to those whose solutions are still in the future.

5.4.1 Sensor Monitoring

The sensor monitoring phase occurs as the Embassy is occupied as the base of local operations. Behind the Embassy is a heliport which will be used to transfer evacuees to the airport. Because the perimeter of the heliport is lined with foliage, there is no natural vehicular or foot traffic in the area. Sensors are set up with seismic and microphone nodes to augment the soldiers patrolling the area. This episode covers the deployment and monitoring of these sensors. The full text of the episode can be read in Appendix C. The main points are summarized below:

- A perimeter is established around the embassy and heliport to extend the range of effectiveness of troops in light cover.

- Sensors are scattered around the area in grid-like fashion.
- Some areas will receive a higher 'noise' level. Analysts can use a 'squelch' knob to adjust the sensitivity of sensors at the individual sensor level or at the sensor network level.
- Sensors are operating with a trip and a corresponding audio clip sent from the sensor microphone.
- Bandwidth use is constrained by adjusting sensor sensitivity and selective use of audio clip transmission.
- An Army patrol in the area is picked up by the sensor network, triggering a Type I error.

5.4.2 Checkpoint

In the checkpoint event, we feature the sensors picking up audio data from vehicles to use for identification. The checkpoint is a typical component of urban operations and we felt there would be opportunity to explore the use of sensors for data gathering, cataloguing, and identification as well as event detection and variation from an established baseline. The main points of the checkpoint are summarized below; the full text can be read in Appendix D.

- Establishment of multiple checkpoints using unattended ground sensors.
- Sensors record audio signatures from approaching and idling vehicles at each checkpoint.

- Analyst working for S2 notices increased percentage of large vehicles going through checkpoint. He alerts the checkpoint about this.
- Checkpoint soldiers find a truck with explosives, confiscate them and detain the driver.

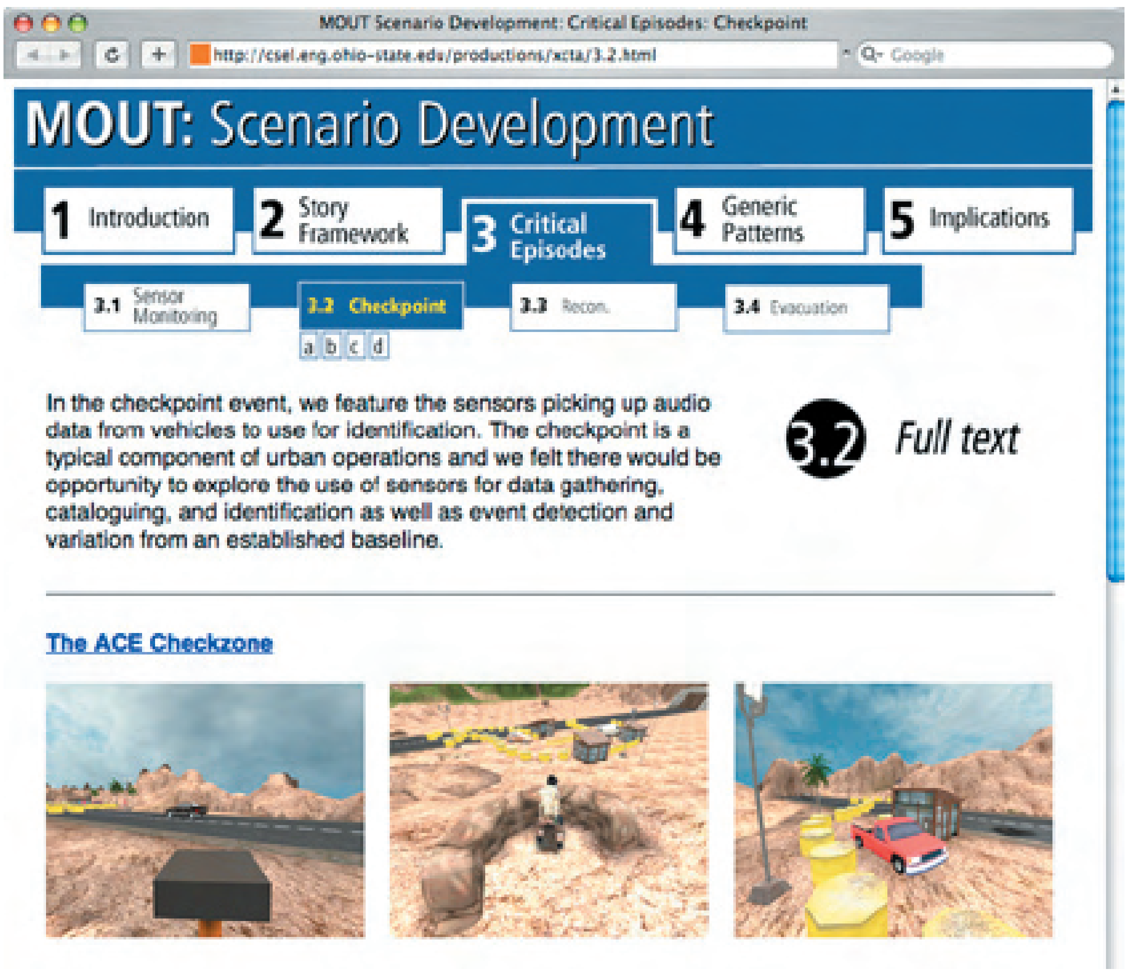

Figure 5.4: Section 3 of the Topic Landscape showing the checkpoint episode and screenshots from our work with the video game editing engine. © Copyright 2005 by Josh Schoenwald and David Woods.

5.4.3 Reconnaissance

For the reconnaissance event we focused on use of the audio in monitoring feedback from sensors placed in different buildings. Another main idea is enemy adaptation. In our scenario we show how this adaptation undermines friendly efforts to catch a group of men making bombs. This event also touches on the use and re-tasking of sensors, demonstrating the flexibility of the same units being used for multiple purposes. The reconnaissance event consists of the following main elements, with the full text available in Appendix E.

- One area of city is suspected of harboring militant groups, patrols are dispatched to investigate and place sensors in buildings.
- One building's sensors register significant activity late at night, which seems to be mostly male voices.
- Sensors are collected from other buildings and set up as a network in the suspected building. They find most activity is in the basement.
- Commander assigns patrol to investigate building, finding suspicious materials.
- Stakeouts are futile, the men to not reappear and all materials are gone; no one is apprehended.

5.4.4 Evacuation

The evacuation is the culmination of actions from other scenes. Here we track the progression and adaptation of the enemy. In one instance they were found in a building, then they abandoned the building, then they were caught at a checkpoint, and here they get as far as placing a vehicle near the embassy with the intent to detonate a vehicle-borne improvised explosive device (VBIED). We also emphasized coordination between multiple checkpoints and sensor networks. A summary of the evacuation is below, with the full text available in Appendix F.

- U.S. troops prepare for evacuation of civilians.
- Use of large trucks mostly abandoned at checkpoints because of frequency of being searched.
- Analyst notices similar vehicle types at multiple checkpoints simultaneously; alerts checkpoint patrols that security may be at increased risk.
- Checkpoint patrols search vehicles thoroughly and find materials that could be used to manufacture bombs.
- Sensors are reallocated from buildings to surrounding area of embassy.
- Abnormal sensor trips & non-responding sensors indicate activity at night, patrols apprehend 4 men with IEDs.

5.5 Generic Patterns

Section 4 of the Landscape features generic patterns which act as the support structure for the critical episodes outlined in section 3. Following our Cognitive Task Analysis we organized our knowledge into two main categories. First we defined critical support functions which relate to the use of new sensor technologies in the domain. They describe specific needs that must be addressed in the MOUT domain and therefore point to opportunities for new sensors to have a real impact. However, these functions must be supported at some level, regardless of the capabilities of new sensors to provide such support. The second category describes complicating factors which are endemic to the urban terrain and which will likely play a role in the effectiveness and implementation of sensors. Rather than functions, these elements provide the backdrop which characterizes MOUT.

5.5.1 Critical Support Functions

Navigation is a sizable problem in MOUT, partly because the terrain is complex and relatively unknown, and partly because it can be radically redesigned by only a few mortar rounds. This creates complexity in maneuverability as well as definition of unit boundaries requiring knowledge of one's orientation to the environment and friendly forces.

There is a need to cross-reference landmarks, targets, and locations across units and echelons to enable representation in a way that helps coordination activities. Unit boundaries must also be coordinated despite the unpredictable and unstable terrain, not to mention asymmetric enemies who will try to exploit this. Because the tempo of urban operations can change so quickly, it is difficult to assume the accuracy of information soon after it is reported. In MOUT, expectations can be difficult to interpret, however necessary for expertise which is tuned to the future.

Ease of mobility for enemy forces is one of their most important assets. They use intimate knowledge of the terrain to dart in and out of buildings, passageways and attack from all directions. Limiting these tactics is key to engaging the enemy on our terms, rather than theirs.

Cutting off routes of escape and approach is a critical task. Isolating areas of the battlefield creates certainty which grants leverage and allows friendly troops to better control the flow of operations. Tracking enemy movements and patterns provides insight which allows more accurate forecasting of enemy actions. Being able to strategically modify the urban environment requires an intimate understanding of the battlefield, beyond what maps can provide. It requires characterizing the changing environments in terms of affordances for friends and foes.

One of the most significant characteristics of MOUT is the difficulty in distinguishing civilians from combatants, since often there are no identifying characteristics before attack is made. Urban combat also puts incredible strain on the local infrastructure which in most cases must be maintained to support civilians.

Because of the ease with which combatants can masquerade as civilians, it is not uncommon for them to use 'bait and trap' methods to catch friendly troops by surprise. Successful delusions violate assumptions which upset mental models and require subsequent adaptations (Woods and Shattuck, 2000). Adding to the goal conflicts of MOUT, the preservation of local infrastructure is also important to mitigate the suffering of those not actively involved in the fighting and to keep them from getting involved. Specific actions (or a lack thereof) which are seen as aggressive or unnecessarily intrusive or violent can trigger such phenomena which swiftly effect the nature and tempo of the battlefield. The complexity of MOUT also reminds us of the need to assure the integrity of available resources such as ammunition, fuel, food, and Psychological Operations (PSYOPS) for friendly troops to accomplish tasks that are difficult to predict and often change drastically with little to no notice.

5.5.2 Complicating Factors

The urban environment is constantly changing. Both physical and human elements cause unpredictable changes in tempo which require changing response modes and reaction times. Different operational tempos in different parts of the cityscape can cause mis-synchronization across units. The speed of decisions and situations can change unpredictably among high intensity, low intensity, crowd control, and humanitarian situations. This requires shifting model boundaries and more importantly, knowing when and how the shifts should be made. The urban environment contains highly adaptive situations with fast-learning adversaries. Tactics that work once very often won't work twice. Thus, repeated practices will not only fail to augment the situation, they will exacerbate it.

Physical structures in the urban environment can be used effectively to drive the modus operandi. Controlling the utilization or destruction of these structures is crucial for success in MOUT. Urban terrain changes quickly and is re-designable. Identifying buildings knowing only their outward appearance poses problems when buildings are disfigured or destroyed. Not only is it more difficult to identify structures, but the physical terrain changes as well, which affects traversability.

Urban settings are vertical, multi-tiered environments. Not only must the warfighter look laterally; but high stories, rooftops, and basements are effective cover for snipers and other attackers. Operations can also be channeled along narrow lanes due to limited fields of view, limited fields of fire, and constricted avenues of approach. This can restrict movement in unexpected ways and provides advantages for the enemy if exploited. Resource management is difficult on complex and unstable terrain. Supplies such as ammunition, fuel, and food are difficult to resupply, and there is greater risk to soldiers if this falls short.

Urban environments are exceedingly complex and unstable, which means that many actions have unintended consequences. These consequences can change the shape, scope, and survivability of a situation with fantastic speed.

Public hostility is highly volatile and can be swayed by friendly or enemy actions. Maintaining good relations with civilians can greatly improve the effectiveness of friendly troops occupying a city. It is often difficult to know that you have done something to anger civilians until they react. Additionally there are varying rules of engagement and opponents who fight your rules of engagement. Asymmetric opponents can gain advantages by using different fundamental tactics which violates assumptions and challenges mental models, posing a risk to friendly forces. Local groups fighting amongst each other can have ancillary negative effects as aggression can shift or increase the danger to friendly operations of an otherwise safe area.

CHAPTER 6

THE AUTOMATED CHECKZONE

Continuing with the Topic Landscape as a tool for collaborative envisioning, we used the critical episodes and generic patterns gleaned from the CTA to more fully depict the value of such methods and tools in re-imagining a particular aspect of the MOUT domain. On the evening of March 4, 2005, Italian journalist Giuliana Sgrena was traveling by car to Baghdad International Airport after being held hostage for one month. She was accompanied by Italian Intelligence Officer Nicola Calipari on a treacherous highway known to be one of the most dangerous in Iraq. As the vehicle approached a U.S.-operated checkpoint, the vehicle was allegedly instructed to slow down, and when it did not it was fired upon. The gunfire left Mr. Calipari dead and wounded Ms. Sgrena. This incident received copious media attention and became a public window into the checkpoint operating procedures. Following an op-ed in the New York Times (Fick, 2005) from a former marine describing the double-binds in which checkpoint workers are often embroiled, we focused our continuing analysis on this aspect.

As it relates to MOUT and sensor technology, the current military checkpoint (CP) does not particularly lend itself to the immediate introduction of small sensor units. Although military operating procedures are difficult to obtain and usually classified, the basic notion is that vehicles are stopped and searched as they approach a designated marked location.

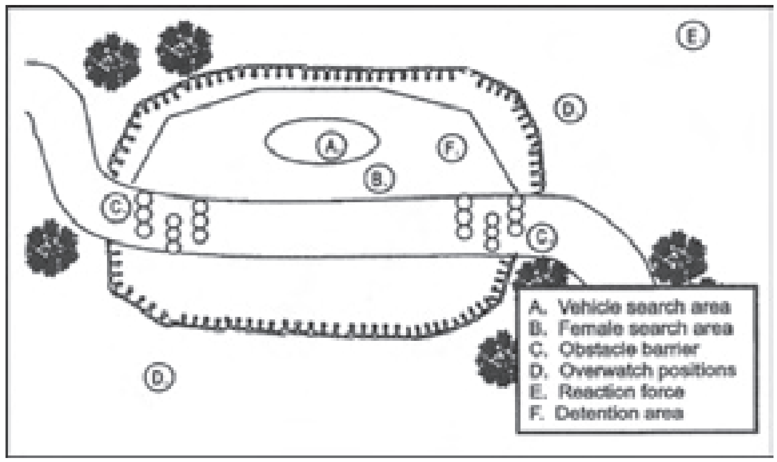

Figure 6.1: Typical Military Checkpoint setup. © 2005 GlobalSecurity.org (http://www.globalsecurity.org/military/library/policy/army/fm/17-98/appc.htm) Used with permission.

Generally speaking there is little if any advanced notice of what sorts of vehicles are approaching, so each vehicle must be treated as a potential threat until searched. Using this topic as the basis of exploration is not about asking how sensors could be employed in checkpoints, but rather asking how the idea of a checkpoint can be re-imagined as a concept. This allows for the natural integration of sensor and other emerging technology to come to the forefront when coupled with an understanding of complicating factors and practical challenges faced by soldiers in the environment.

The notion of an automated checkzone represents this further exploration. As we more completely flesh out the checkpoint sub-section, new narratives emerge which play out in this more tightly-constrained domain. The events which drive the action of this automated checkzone show how, given the constraints of the MOUT environment and the generic patterns observed to be at work, emerging sensor technologies could provide part of an alternative solution of how to operate a checkzone.

Instead of the resolute 'checkpoint' moniker, we have imagined a checking area called the ACE (Analysis, Confrontation, Enforcement) Checkzone. The ACE checkzone is divided into three distinct zones. Each zone serves to collect information about the traffic as it approaches a sensitive area and assess whether or not additional thorough searching is necessary. The need for this is underscored by current risks and CP logistics, including the fact that most vehicles do not pose a threat and should be allowed to pass through the checkpoint, and in many areas there is significant risk of vehicle-borne improvised explosive devices (VBIEDs) which threaten not only the security of the area beyond the CP, but the personnel and infrastructure of the CP itself.

6.1 Tom Clancy Helps Build an Animock

To complement the descriptive narratives, we folded our exploration of the ACE Checkzone into an animock. Instead of using expensive 3-D modeling and animation software, we used the game editor built in to the popular video game:

Tom Clancy's Rainbow Six 3: Raven Shield. We have used video game editors in other projects as well (Voshell, 2005), and they're being used more frequently (Wang et al., 2002) because they offer a cheap means of providing realistic environments to illustrate the components of the scenarios around which they are built. In our case, the Raven Shield game is militaristic in nature, and comes with a number of different environments, from desert terrain to cities and towns. All of these can be edited and the animation is built right into the game engine, so achieving movement is as easy as playing the version of the game you've just modified. For these reasons it made much more sense to use this preexisting engine since it saved us a considerable amount of time and we didn't need the exacting specifications as required in our previous work with the NASA animock.

Figure 6.2: Screenshot from the Raven Shield video game simulation. © Copyright 2005 by Josh Schoenwald and David Woods.

The videos we created from the game (http://csel.eng.ohio-state.edu/productions/xcta/3.2a.html) are meant to serve as instigators for field practitioners (both sensor and military) to gain an 'in-situ' perspective which frees them from their designer's perspective and allows them to visually observe one interpretation of both enemy and friendly forces adapting to the constraints of the MOUT environment. The purpose is to facilitate discussion on the topic by those involved, and so our videos and screenshots reflect the three narratives underlying our description of the ACE Checkzone. Each video works in concert with the narrative to provide a more complete picture of the scene and to spark discussion which will hopefully lead to new designs rooted in supporting the true demands of MOUT.

6.2 Analysis Zone

The first area vehicles approach is the Analysis Zone. It is defined by a set of small, fairly hidden sensors located off the road. These sensors are controlled by soldiers and operated remotely to evaluate the approximate size, body style, and weight of vehicles as they approach and pass. The soldiers who control these sensors are hidden from view, operating downstream from oncoming traffic near Zone 2. Vehicles entering the Analysis Zone do not stop at all and are instructed by signage to slow down as they approach. This zone employs computer algorithms using sensor data to analyze the weight of oncoming traffic and compare it to expected values and ranges of similar vehicles. This information is passed on to Zones 2 and 3 for further interpretation. If a soldier monitoring vehicles in the

Analysis Zone suspects something is not right, he can flag the vehicle to alert the person working the Confrontation Zone of the possible threat.

The purpose of the Analysis Zone is to collect information about vehicles that help soldiers make decisions on whether certain vehicles are more likely to be a threat. The Analysis Zone is designed so that traffic flow is not affected which explains why such limited information can be captured at this stage. The Analysis Zone will easily catch vehicles whose weight or weight distribution is unique for some reasons. These reasons will continually evolve; at first they might be severely over-weighted or mis-weighted vehicles, later they might be vehicles who are significantly lighter than expected. In any case, it will be near impossible to correctly flag vehicles whose weight characteristics fall within the norm of most other vehicles. The enemy will likely use tactics to evade the cameras when they can, to prevent that information from being recorded.

While it is not possible to guarantee that every vehicle which poses a threat is flagged, the information recorded into the database is still useful in tracking vehicle movements around the area and fluctuations in weight of the same vehicle that occur over time. Also, the Analysis Zone can only create flags based on vehicle-related alert signs. Of course, people inside those vehicles can also pose a threat in and of themselves. The detection of such threats is one of the goals of the Confrontation and Enforcement Zones.

6.2.1 Narrative

To more fully understand the implications of this Analysis Zone, we created a short narrative to illustrate how the logistics could play out.

In the early morning hours, traffic is slow, averaging about 1-2 vehicles per 5 minutes. During this time, every vehicle that passes through the Analysis Zone is recorded and logged. As the morning wears on, traffic steadily begins to increase as people begin their morning commute. Soon, it is no longer possible for the sensors to gather data on every vehicle as they pass. Using their experience as a basis, soldiers direct the sensors to monitor the vehicles they think are the most likely to pose a threat. Over the next 30 minutes, 40 vehicles are analyzed. The soldier in charge of monitoring the sensor feedback noticed that 2 of those vehicles differed in average weight (as compared to typical weights for similar vehicles on the same roadway); one weighing 1500lbs over the average and another one 900lbs under the average. Also, 3 vehicles were found to have abnormally distributed weights which differed significantly from what the soldiers had been used to seeing. These vehicles were 'marked' in a database with identifying information (make, model, color, etc) to alert operators at Zones 2 and 3 that these vehicles are considered to pose an increased risk.

Figure 6.3: Screenshots from the Analysis Zone narrative simulation. This shot is showcasing how vehicles can hide from view alongside other vehicles. Video can be viewed at: http://csel.eng.ohio-state.edu/productions/xcta/3.2b.html

These methods worked remarkably well for about 1-2 weeks. Numerous cars were flagged and this information proved useful in stopping and checking vehicles in the Enforcement Zone, as well as directing questions for soldiers to ask when the vehicles enter the Confrontation Zone. But the enemy soon realized the questions they were being asked about their payload and intentions meant that somehow data were being collected before they arrived at the Confrontation Zone. Over this time the instances of vehicles flagged from the Analysis Zone had declined. It was discovered that the enemy had noticed the sensors and were employing various strategies to hide from them. These included operating in low-visibility conditions, and even attempting to hide during increased traffic by surrounding themselves with other vehicles. In response to this, soldiers attempted to camouflage the sensors and changed their location frequently to better hide them. Additionally, because the enemy had not yet figured out that vehicles were being assessed based on weight, increased vigilance and scrutiny during especially vulnerable circumstances (night, low visibility, etc) was an effective means of mitigating this threat. However it's clear that at some point the enemy will figure out their weight is being measured, and this will require a further adaptation from the soldiers to maintain effectiveness.

6.2.2 Generic Patterns

This narrative demonstrates the potential utility of this new form of check-zone. As time goes by, it is conceivable to think that once the enemy realizes the cameras are recording vehicle weights, they will cease to transport heavy items, instead opting to carry smaller items in more vehicles. This might mean that instead of looking for anomalous weights and distributions, soldiers are now looking for caravans of similarly-weighted vehicles or vehicles with similar weight distributions. This type of evolution will be continuously important as long as there is an intelligent adversary.

The tempo of the urban environment is constantly changing. The advantage of the sensor cameras in the Analysis Zone is that they provide a means for the soldiers in subsequent zones to direct their attention (Woods, 1995) towards vehicles that may be a greater threat. It is important to note that the algorithms used by the sensors are not attempting to make decisions on the severity of the risk involved with each vehicle. Instead, these algorithms analyze available data and present them in a form that has real meaning to the soldier as he tries to assess the fluctuation of threatening and non-threatening situations. The direct information provided by the sensors (average deviations from a baseline, frequency of such deviations, trends, etc.) allows anomalous instances to become naturally obvious, while at the same time providing the soldier with the context explaining the anomaly. For instance, a vehicle weighing 2000lbs more than the average weight for that vehicle type might be a non-issue if the soldier sees that it's a friendly supply truck. It is imperative that the soldier have control and be able to understand what the algorithms are doing and how they relate to his or her goals (Woods, 2002).

6.3 Confrontation Zone

After passing through the Analysis Zone, all vehicles enter Zone 2: the Confrontation Zone. Drivers are instructed via road signs and concrete or other barricades to slow down. This multi-lane (depending on traffic concerns for the road) controlled area is similar to current military CPs in that it requires each vehicle to stop. Barricades are in place to prevent each vehicle from proceeding. Again, soldiers are located in overwatch positions flanking the kiosk. While vehicles are stopped, drivers are instructed to speak into a microphone and converse with soldiers. Their voice and image are recorded and stored in the database, along with any identifying information as gathered. While this is going on, embedded in the kiosk structure are cameras which take pictures of the vehicle and its license plate. Chemical readouts are obtained from the vehicles indicating the presence of known explosives and materials. Also, microphones record the sounds of the engine idling. These data are compared to known database entries which can indicate it certain vehicles have been previously identified at this or other checkpoints. Depending on this further analysis, each vehicle is either allowed to continue on its way, or is directed to enter Zone 3.

This area in the ACE checkzone is the first contact of soldiers with vehicles traveling along a highway. With advances in sensor technology, it becomes possible to record identifying elements of people and vehicles which can then be tracked across locations and time. Having this information available to soldiers helps them make decisions on the presumed risk of each vehicle, and also gains recordable insight to enemy tactics as vehicles are searched.

6.3.1 Narrative

A narrative explaining the function and context of the Confrontation Zone follows below.

Traffic through the area is modest this afternoon. Most vehicles arriving into the Confrontation Zone have been analyzed prior to reaching the kiosk. From this information, soldiers can direct their questions to vehicle occupants regarding weight and distribution. An average of 5-10% of vehicles are directed to enter Zone 3, while most are allowed to continue. At one point an ambulance enters the zone and stops at the kiosk. The driver looks anxious, and the lights and siren are both flashing. The driver says he is in a hurry and must get to the hospital because there are two men in the back who have been seriously injured by gunfire. Readings confirm that this same vehicle 4 hours earlier was seen, with a different driver, carrying no passengers, at another location 10 miles away. Now, the vehicle is 650lbs heavier and is detected to be carrying large amounts of ammonium nitrate. Infra-red scanning reveals that there are indeed 2 people in the back of the ambulance, however their condition cannot be evaluated. The soldier makes the decision to send this vehicle into Zone 3 instead of allowing it to continue.

Figure 6.4: Screenshots from the Confrontation Zone narrative simulation. This video shows operation of the Confrontation Zone. Video can be viewed at: http://csel.eng.ohio-state.edu/productions/xcta/3.2c.html © Copyright 2005 by Josh Schoenwald and David Woods.

After a month or two of operating the Confrontation Zone, incidents of VBIEDs and other attacks beyond the checkpoint began to escalate again. It was discovered that the enemy began using a multi-vehicle strategy where they would send one vehicle expecting it to be stopped and searched, while in communication with another vehicle. The other vehicle would be 100-200 meters away and take advantage of the information being passed to them or simply use the distraction of the first vehicle to slip by uncontested. In response to this, soldiers working the checkzone began listening to foreign radio transmissions that originated from and were being sent to vehicles in the checking area. This method was an effective adaptation to the behavior exhibited by the enemy at the time. Future plans call for the ability to concurrently monitor activity in all 3 areas of the checkzone to better recognize enemy cooperative strategies.

6.3.2 Generic Patterns

The second narrative explores the difficulty in assessing intent, which is the key to determining if a person is a threat. This situation could have been further complicated if we assume there were no abnormal chemicals found and yet the people in the back of the ambulance were on their way to a rendezvous. The idea is not to build a system to eliminate these contingencies, but rather to make enemy adaptations stand out against a background of fair-minded citizens.

Urban environments are particularly dangerous because it is easy for the enemy to blend into the environment and hide amongst throngs of innocent citizens. Indeed, without a uniform or dedicated structure, the two are in essence the same. This makes is very difficult to track movements and patterns among people. A better way to think about it is based on actions, which is the goal of the Confrontation Zone.

The advantage of having an unmanned checkzone is that you significantly reduce the risk of casualties from explosives or other attacks on the checkzone personnel or infrastructure. If someone states they are not carrying ammonium nitrate, yet the chemical sensors pick up a large amount, this is a good indication that person needs to be questioned further. Also, recognizing vehicles that have been recorded in other locations could lead to a more thorough search or questioning. These types of finds become rather overt given the technology and are likely to reduce attacks using these tactics, techniques, and procedures (TTPs). The challenge therefore is to understand how the enemy is adapting and where, when, and how to expect the next attack. While the chemical sensors and cameras can pick up data about the driver and vehicle, what's difficult is to determine if someone is telling the truth when no other data give any indication that something might be a threat. This is one area where the ACE Checkzone is no better than a traditional CP, however the data collected on the vehicle can still be helpful in learning more about the enemy's TTPs. The longer the checkzone is left in place, the more chances the enemy will have to exploit vulnerabilities, and the more subsequent adaptations will be required to account for those. Part of operating in adversarial environments is understanding that your adversary will continue adapting to your adaptations, and the enemy you're facing now is not the same enemy you faced 2 months or even 2 weeks ago. The following depictions illustrate that point.

6.4 Enforcement Zone

The 3rd zone is the Enforcement Zone. Most vehicles will bypass this zone completely. However, those vehicles which have been flagged in either of the first two zones will, at the discretion of the soldiers working at the Confrontation Zone, be sent to the Enforcement Zone before being allowed to continue, if they are at all. The Enforcement Zone also contains a kiosk, and space for a few vehicles to be stopped and inspected. When vehicles enter this zone, they are continuously under surveillance by soldiers flanking the road in protected areas. Armored vehicles with weapons trained are visible near the roadside to deter uncooperative activity. Also, cellular telephone reception is blocked with the use of jammers, as this is a popular means for detonating IEDs and other explosives. Once stopped, drivers and passengers are asked to get out of the vehicle. Only then are they approached by uniformed soldiers who question and search them, as well as search the vehicle. At this point, vehicles may be asked to turn around, allowed to continue, or held for further inspection as necessary. Because all vehicles entering this zone are considered an elevated danger, soldiers are prepared to fire disabling or lethal shots to protect themselves from aggressive behaviors.

The advantage of the Enforcement Zone is that it allows a thorough inspection of particularly suspicious vehicles while still maintaining the flow of traffic. It also restricts contact from soldiers to a safe distance to prevent IED explosions which destroy the entire checkpoint and personnel. Most vehicles are benign and are allowed to pass without thorough inspection, however the bypass lane allows inspections to be as thorough as necessary to ensure the safety of the solders. It effectively removes the checkpoint as a target for VBIEDs, due to the lack of personnel on the roadway and the presence of armored vehicles which can disable or destroy aggressive vehicles from a short distance. Additionally, the background information that accompanies each vehicle entering the Enforcement Zone allows the soldiers to make comparisons across time and distances and to better assess the threat posed by each vehicle.

The Enforcement Zone is very effective when the vehicles entering the area are annotated with comments describing some of the history and reasons for suspicion. This information can be tailored to meet the needs of checkzone workers as necessary. For instance, if it turns out to be more helpful to know how many other checkpoints the vehicle has been through, that information could be provided. This information helps guide the soldiers working the Enforcement Zone to learn about what might be important clues to adversarial behavior. However, without any sensor readings or recordings or comments, the Enforcement Zone essentially becomes a traditional CP and is much less effective as the 3rd piece of the integrated ACE unit.

6.4.1 Narrative

A third, separate narrative explores how this could be used to thwart IED attacks and checkpoints and to discover IEDs before they are detonated.

Vehicles at this time were being sent to the Enforcement Zone at a rate of about 10 per hour. This represented approximately 14% of all vehicular traffic. Some vehicles sent to Zone 3 were observed to be carrying large loads of food and supplies, and were sent there because of their vehicles' excessive weight and the inability of the drivers to verbally communicate with the soldiers in Zone 2. After examining the payload and questioning the driver, all of these vehicles were allowed to continue. Another large truck is directed to enter the Enforcement Zone, and it appears to also be carrying large amounts of produce. Reports indicate that just like many of the previous vehicles, this one was also overweight and there was an inability to communicate with the driver. The one difference with this vehicle is that it had passed through the same checkzone in the early morning hours, and was allowed to proceed after inspection. When the vehicle is stopped, the driver is asked to get out and does so, along with 2 other passengers who were not in the vehicle when it came through earlier. The truck's payload of dirt, claimed to be for a construction project is searched. Buried in the mound are relatively small containers of explosive chemicals with electrical wire running under the car to the engine block and gas tank. The vehicle occupants are further detained while the area is cleared and the vehicle disarmed. It is then moved off the road to make way for further inspections.

Figure 6.5: Screenshots from the Enforcement Zone narrative simulation. This video shows the Enforcement Zone as a truck driver is searched. Video can be viewed at: http://csel.eng.ohio-state.edu/productions/xcta/3.2d.html © Copyright 2005 by Josh Schoenwald and David Woods.

The Enforcement Zone identical in many ways to traditional CPs. The main difference is that vehicles that enter this zone are already suspicious for one reason or another. After weeks of operations, a small sedan is directed to enter the Enforcement Zone very early one morning. Traffic is nonexistent (5-10 vehicles per hour) and because of this soldiers had adopted the policy of thoroughly checking every vehicle in Zone 3 no matter the readouts from Zones 1 and 2. This particular vehicle belonged to a commuter. It was seen passing through the checkpoint 12 times in the past 3 weeks. This time however, the driver seemed agitated and anxious, and during a search of the vehicle a large cache of gunpowder and 10 automatic rifles were found under the seats. After-Action Reviews (AARs) revealed other similar occurrences, indicating that the enemy had begun using vehicles that have cleared security multiple times to hide their actions. This trend was revealed to be an effective means of clearing the checkzone with as little scrutiny as possible.

6.4.2 Generic Patterns

This narrative plays on the advantages of priming checkzone workers about the history and likely type of threat posed by each vehicle as it enters the Enforcement Zone. While this poses a clear advantage, there is a risk of losing vigilance with complacence as many vehicles begin coming through with the same types of signatures. It will take effort to treat each vehicle separately and to not simply rely on recommended actions from soldiers in Zone 1 or 2.

As this narrative exposes, enemy tactics are able to adapt to the situation by intentionally sending multiple vehicles with the same apparent profile in hopes that one of them would get passed through. The ability to cross-reference information from the Analysis and Confrontation Zones and incorporate historic data are ways in which this type of enemy adaptation can be countered.

This sensor information passed along to the Enforcement Zone becomes crucial to giving the soldiers a greater context within which to evaluate the potential threat posed by each vehicle. Without this information, the structure of the ACE Checkzone is stripped of its uniqueness. This is a vulnerability that will be exploited, and will require continued adaptation on the part of the soldier to maintain effectiveness.

CHAPTER 7

ANALYSIS AND IMPLICATIONS

The MOUT domain is an especially difficult candidate for envisioning because of its adversarial nature. Through the development of our Topic Landscape emerged a number of implications that speak to the unique support requirements of implementing new technology in this domain. Specifically with respect to the use of new sensor technologies, we outline the necessity to understand observability and directability (Woods, 2002) and the importance of event recognition as opposed to signal recognition. Additionally, a discussion follows suggesting some ways in which sensors could be used to support these constraints.

7.1 Observability and Directability

Designing the future use of emerging sensor technology in the Military Urban environment requires that the technology be both observable and directable. Observability (Woods, 2002) refers to the visibility of system status and the ability to which it allows people to see things they weren't expecting. This rich understanding enables the human stakeholders to fully understand the bounds of technology and reduce episodes of automation surprise (Sarter et al., 1997) which usually lead to deactivation or discontinued use of relevant technology. Additionally, stakeholders will understand areas where the system is weak and strong, so that its use can be optimized and questioned, as appropriate.

In addition to being observable, sensor systems must also be directable. Directability refers to being able to control the technology as necessary based on knowledge of your goals, the system, and how the system works. This demonstrates the value of observability; when as a stakeholder you need to change something, your model of why and how to do so is accurate. Simply creating observable systems with no commensurate directability does not afford stakeholders the means to make necessary changes.

The consequences of unobservable and un-directable technology have been well documented, especially in the domains of aviation (Sarter et al., 1997, NTSB, 1986), health care (Sarter et al., 1997, Cook et al.,1991) and navigation (Lutzhoft and Dekker, 2002). Poor observability and directability led to failures in these situations because practitioners were unable to gain a true picture of what the systems were doing or make the changes necessary to stave off disaster.

Observability and directability teach us that the issue is not the level of autonomy or authority, but rather the degree of coordination (Christoffersen and Woods, 2002). This is especially true in high-risk, fast-paced, dynamic environments such as MOUT. In this way, parallels can be drawn between previously observed domains and MOUT, showing us that the MOUT domain is equally susceptible to these types of failures. With regard to sensor technology, we must go beyond the mere availability of information (did the sensor go off?), and begin to provide information that helps the soldier perform his or her job. Rather than attempt to replace the soldier's intelligence with intricate, unobservable algorithms, it is imperative that advances in sensor technology be aimed to complement the soldier as the ultimate stakeholder.

7.2 Event vs. Signal Recognition

As cooperative agents, sensors must be able to communicate in a manner that has real meaning in reference to the goals of the stakeholders. These goals are complex and involve the consideration not only of the squad in question, but other squads, platoons, and enemy forces which may be geographically separate, yet critically important. In order to facilitate this communication, sensors must be designed to operate in the perspective of the soldier, not the technologist.

This means the focus and the value of sensors comes in event recognition rather than signal recognition. Sensors are designed to collect data based on a programmed set of parameters. Simply presenting these (raw) data does not tell the soldier any valuable information as it relates to real goals which are more complex than whether or not something crossed the receptive field of a sensor. Interpreting these data through algorithms into assumptions about the nature of such detections ("was the detection caused by a truck or a group of people") is not the correct way to solve this problem either. Automated assumptions are brittle when used in dynamic, fast-paced adversarial situations, where enemy tactics are constantly adapting to pose new threats.

Instead, real advances in sensor utility will come when data collected by these sensors are organized and integrated in ways that make enemy actions apparent. The key is to support rather than supplant the decisions made by the stakeholders. In other words, instead of trying to make assumptions on behalf of the soldier, these sensors should be providing information that makes the decisions easier for the soldiers to make.

7.3 Implications of Generic Patterns

Critical Support Functions

Sensors have the potential to help friendly troops orient themselves not only to the environment but to each other. An oft-unspoken difficulty in MOUT is knowing the precise whereabouts of friendly troops, both in relation to each other, the environment, and known enemy forces. Using sensors as tracking devices or waypoints could help support the need to continuously be aware of one's location as it relates to friendly and enemy forces.

Restricting opponents' mobility is another crucial MOUT function because of the relative ease with which locals can move and hide within the terrain. Sensors placed in swept areas could serve as indicators of the re-emergence of enemy combatants into secure areas. Locals will always have a more intricate understanding of the battlefield and will exploit this advantage. Understanding the need to establish boundaries should guide the use of sensors in this fashion.

Complicating Factors

The tempo of urban warfare is constantly changing. Not only can situations be tortuously banal or blindingly intense, but the transition from one to the other can come quickly and without warning. Sensors are primarily used to gain information about the enemy which prepares friendly troops for appropriate action, so the ability to recognize the escalation (or subsidence) of events more quickly is a definite value. Also, it should be noted the effectiveness of certain sensors can be altered as the pace of action begins to change.

Another critical component of sensors is their ability to be emplaced in strategic locations. The physical environment of urban terrain can be a hindrance to this goal in a number of ways. First, because of the inherent verticality of the domain, placing sensors around the street may not provide effective coverage to higher floors. Additionally, emplacing sensors at these locations can be both difficult and dangerous. The abundance of concrete, steel and other hard materials also limits the effectiveness of and shortens sensor ranges. Unlike forest or desert terrain, explosions and the rigor of combat will cause significant changes in the urban landscape. Bombed-out buildings and torn-up streets can also wreak havoc on the emplacement, use, and retrieval of sensor units.

The urban environment is highly unstable; situations that are benign can become hostile for a number of reasons. Often, attacks on friendly troops can be a side-effect of in-fighting elsewhere in the area. Occupying forces must be wary of their use of sensors to monitor the environment. A civilian group might become hostile if they discover a hidden camera or microphone in their midst. At the same time, different cultures foster vastly different rules of engagement, which can be challenged by the careless deployment of sensor nodes.

CHAPTER 8

CONCLUSION AND FUTURE ENDEAVORS

Scenarios are indeed powerful envisioning tools, and I've demonstrated their prowess in synthesizing CTA results into a form that is tangible and appropriate for practitioners to appreciate. But the usefulness of a scenario depends in large part on the effectiveness of the CTA that precedes it. A CTA which only lists characteristics, however important they may be, does not point to specific avenues of improvement along which scenarios will travel. One must specifically look for the difficulties, adaptations, and interactions that form the dynamics of the environment in order to get seeds to begin scenario development. Scenarios must exist on multiple levels: at the same time capturing intricacies of the domain as well as generic patterns that define the dynamics of work in any joint cognitive system. The domain-specific elements provide instantiations of the generic patterns to play out, which lends credibility to the scenario as a whole. The generic patterns, culled from the Cognitive Task Analyses and research in Cognitive Systems Engineering, provide a level of abstraction that generalizes the problems and provides insight on solutions. Building both of these levels into the scenarios makes it easier to see the link between generic problems (i.e. lack of observability) and the specific manifestations of those problems in the scenario (i.e. sensor units being turned off because of constant false alarms).

The Topic Landscape is a useful tool for supporting collaborative envisioning and scenario development. It enables multiple viewpoints to converge and provide a robust perspective on the evolution of behavior in the field of analysis. The Topic Landscape provides a means for the exploration of many different evolving storylines about a topic. These storylines, woven into a scenario based on the challenges of the field of practice, provide design seeds which speak to the true needs of practitioners. The design of the Topic Landscape allows for one or multiple scenarios to evolve in a particular medium. The Topic Landscape is infinitely extendable, as it can link to other Topic Landscapes to provide a body of research on various related domains. As an always-available shareable resource, it works well as a tool for collaboration. It becomes even more valuable when it is embraced by diverse groups of people who have different areas of expertise. This convergence of perspectives is important because people with different backgrounds will focus on different elements; thus adding insights that will spark others to react. The nature of the Topic Landscape is to open up areas that can be explored by either the practitioners or the technologists who have a stake in the design outcome. It becomes an effective tool for discussions between both groups of people about what is important and how designs can improve elements of the domain. Although I was not able to implement them at this time, in the future it would be trivial to add commenting functionality to pages of the Topic Landscape. This would provide an invitation to practitioners to begin discussion and link to other material related to the work being developed in the Landscape. As the author list grows, hyperlinks could lead off in new directions connecting a plethora of people, technology and work through various means and perspectives. In this manner, the Topic Landscape can be utilized as a platform for bridging the gap between technologists and practitioners. By providing a format for laying out the complexities of the domain and how new technologies might play a role in the future, the Topic Landscape becomes a valuable synthesizing tool for any Cognitive Systems Engineering-based design endeavor.

APPENDIX A

ANIMOCK BLOCKING DIAGRAM

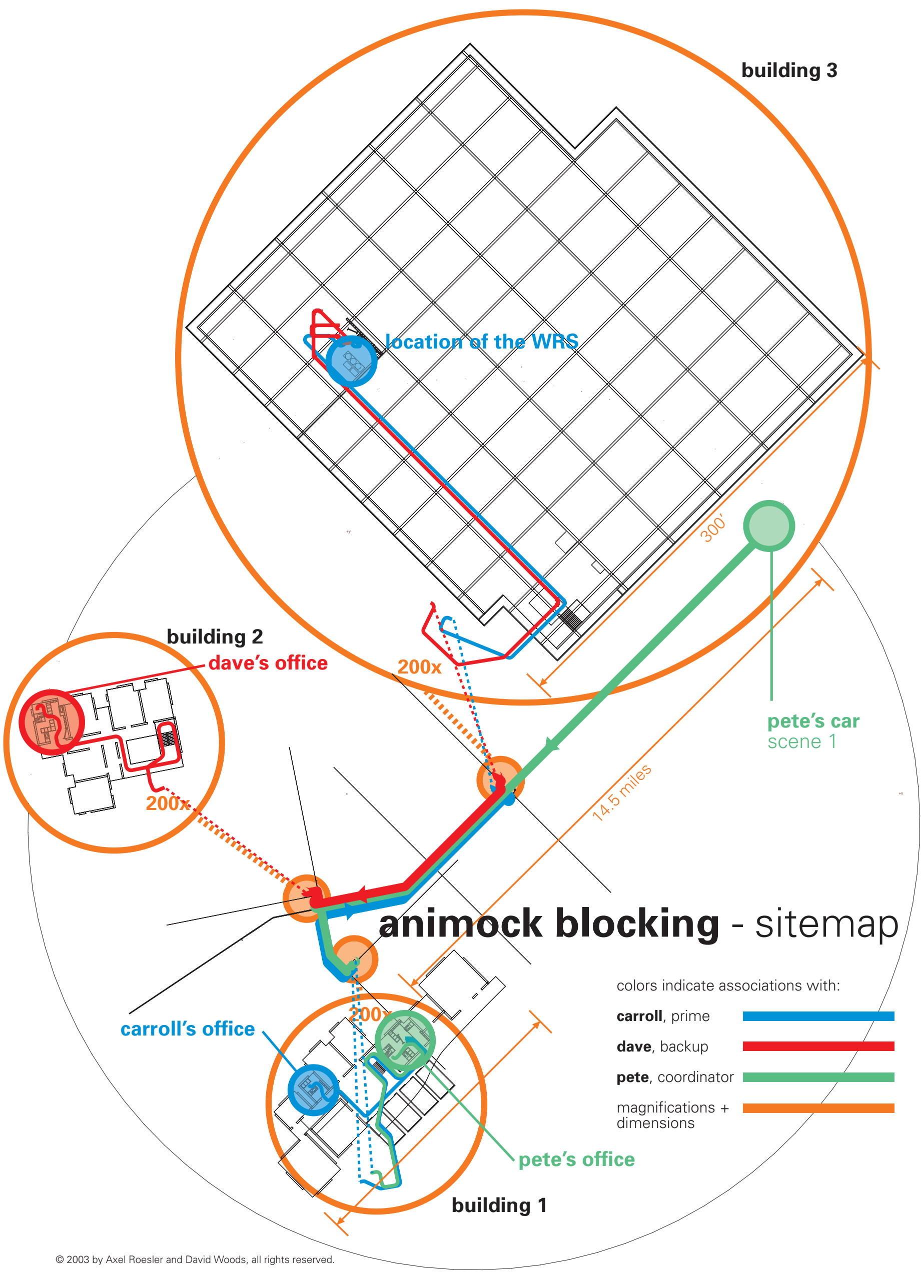

Figure A1: Red, green, and blue color codes on this diagram represent locations and paths of different characters so it becomes easy to see how each moves physically through the scene as time elapses. This god's eye perspective allows you to quickly see the relationships of characters to each other and to artifacts of the stage. © Copyright 2004 by Axel Roesler and David Woods.

APPENDIX B

ANIMOCK PACING DIAGRAM

animock pacing - timeline

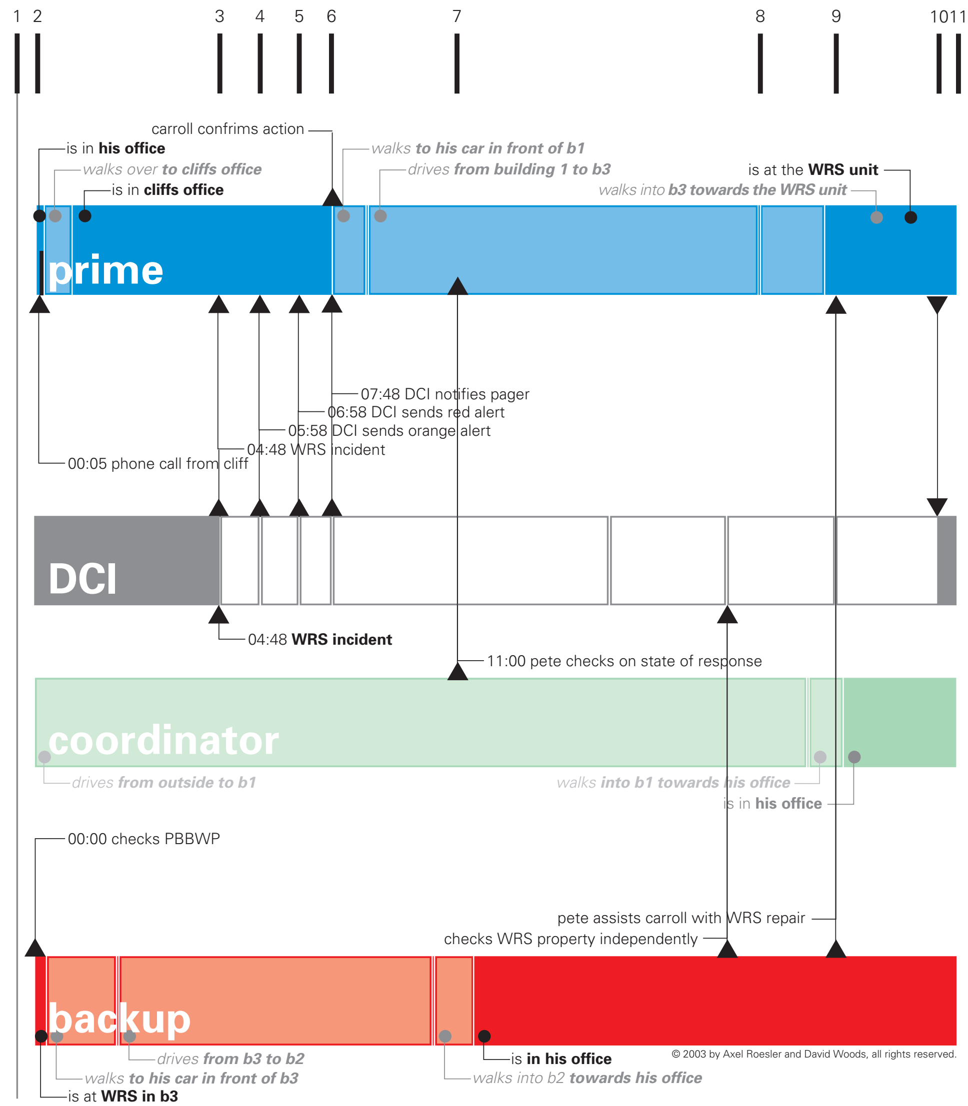

Figure B1: This diagram depicts the temporal progression of four main characters. Characters can be human or mechanical; in this instance one character (DCI) represents a computer network. Coupling the blocking and pacing diagrams allows you to see when different characters will intersect at specific physical locations. © Copyright 2004 by Axel Roesler and David Woods.

APPENDIX C

FULL TEXT OF SENSOR MONITORING SCENARIO EPISODE

The current S2, upon arriving at the Embassy and establishing his center of operations, directs the establishment of a partial sensor perimeter around 2 sides of the heliport which are not expected to see major traffic. The company commander responsible for perimeter security directs the sensor team in the exact placement of the sensors in order to augment his patrol routes. Together, the patrols and sensor array should provide information to the S2 about the frequency and nature of perimeter intrusion attempts. The sensors will also allow for economy of force around the embassy and allow other forces to be used elsewhere in the city. Most activity is expected to be on the front two sides of the embassy, so the predominance of the security company guards and patrols are oriented here. [Sensors are not necessary where there are enough soldiers].

The sensor team places sensor units around the perimeter area, arranged so the receptive fields of the sensors overlap on multiple dimensions. This makes it easier to determine the size and direction of movement of something through the field of sensors (Figure C1 shows an example from multiple angles). When the sensor team finishes, they report back to the embassy and are reassigned. Another patrol (non-sensor experts) is provided with the equipment to monitor the newly emplaced sensors. They will continue to take orders from the company commander. The analyst working for the S2 is in the Embassy / command center, and is tasked with many jobs, one of them being to monitor the feedback from these sensors and other collection assets.

In front of the analyst is a computer screen with an area map that shows the general locations of all the sensors. While monitoring the network, he begins to establish a baseline of behavior that is assessed as "normal". This essentially corresponds to the 'noise' factor when trying to distinguish real intrusions from false alarms.

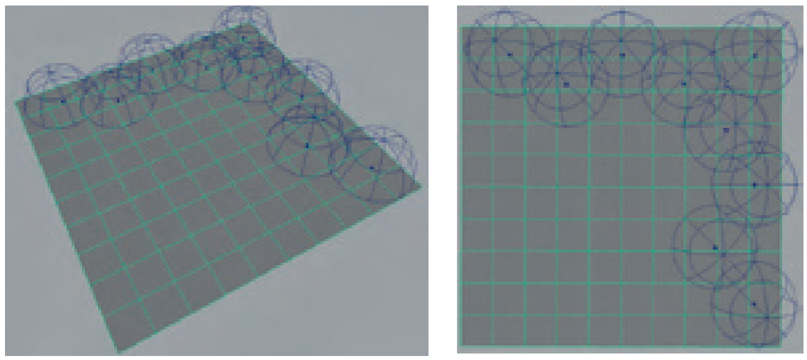

Figure C1: Diagrams of potential sensor deployment layouts.

As the analyst monitors the perimeter network, he is aware through knowledge of the terrain as well as incoming reports from field patrols that certain areas are more or less likely to attract significant levels of ambient noise. This noise may be due to nearby non-threatening traffic, animals, or structures which affect the response of the sensors. To adjust the overall network to a baseline sensitivity, the analyst has a squelch knob he can use to increase or decrease the sensitivity of individual sensors. Doing this allows him to calibrate each sensor so it returns a certain level of noise. Additionally, there is a global squelch knob that allows the analyst to adjust the sensitivity of the entire network as a whole.

While monitoring the network, each sensor is sending back information as a blip, or trip when it picks up something in excess of the sensitivity level set by the squelch knob. In addition, a second threshold is set. When this higher threshold is exceeded (as determined by the amount, speed, or frequency of information picked up by the sensor), audio data is also picked up and sent along with the 'trip' information. Leaving the audio off when not being used helps conserve battery life of the sensor, and also helps mediate bandwidth constraints.

Bandwidth is a significant issue, and it should be noted that just because a certain sensor is sending data, that doesn't necessarily mean there's not more data that could be sent. One way to mediate this trade-off is by the use of the squelch knob which helps reduce type I errors and consume less bandwidth. Additionally, if a certain sensor or group or sensors shows unusual activity, relative sensitivity of other sensors can be reduced temporarily in order to devote more bandwidth to exploring the problem area.

This increased bandwidth can be used to listen to audio clips from the sensors in question, and possibly send a patrol to inspect if the information warrants such an investigation.

As the analyst monitors the network (along with doing other tasks) he notices the response level for two sensors increases to the point that audio data is captured and is sent across the network. As he listens, he can make out human sounds, but nothing that conclusively tells him what he's hearing. As a precaution, he contacts the S2 who in turn contacts the security company commander for the patrol. A patrol is contacted and their position is relayed back to the analyst, who confirms the patrol is at the same location as the apparent intrusion. Further communication reveals conclusively that the only presence in the area is from the friendly patrol.

The incidence of sensors picking up friendly soldiers can be partially mediated through the use of the squelch knob, which allows one to turn down the sensitivity of sensors in more-heavily trafficked areas. Because in a general sense we know where we have a larger presence of personnel, we can infer areas where it is more likely that certain sensors are picking up friendly soldiers, and areas where this is less likely to be the case. Another possible way to deal with this problem is through employment of each soldier as a node in the network, so that sensors would recognize friendly soldiers as nodes rather than intrusions. Each soldier operating around the sensor network area would wear a sensor unit on their person. The network would dynamically re-localize with the addition of the soldiers as nodes in the network and be able to track their movement throughout the area. This eliminates the phenomenon of friendly soldiers (at least ones with the sensors and known to be in the area) being mistook for the enemy and also helps with tracking. Work on this is being done by MIT (Bachrach et al., 2004). Of course this raises other issues such as: malfunction of soldiers' transponders, transponder spoofing, etc.

APPENDIX D

FULL TEXT OF CHECKPOINT SCENARIO EPISODE

In preparing for the evacuation, the commander decides to set up a series of checkpoints to monitor the vehicular traffic through this area towards the embassy. He tasks both of his maneuver battalions to establish static and squad-size mobile checkpoints along main streets in their areas. The checkpoints are to monitor for anything that might pose a threat to the pending evacuation mission.

At the static checkpoints, the platoons emplace a barricade that partially blocks the road, constricting traffic down to one lane, and also establishes a network of ground sensors near the checkpoint area. These sensors are recording audio from vehicles as they approach and wait at the checkpoint. Instead of trying to pick up voices, these recorders are interested in the engine sounds as they move and idle. The idea is to register the relative number and size of vehicles that are approaching, and to identify a signature that represents a certain type of car (really a certain type of engine). That signature could potentially be used in other situations to identify types and potentially numbers of vehicles. For instance, a sedan will have a different audio signature than a truck. Additionally, a Toyota is likely to have a different signature from a Volkswagen, although determining different makes would require a significantly robust signature both while recording and comparing. These recordings will be used to establish a baseline of activity for long term trending that will be able to spot alarming trends that happen too slowly for humans to notice (i.e. over many hours, across multiple shift changes, or over multiple days).

At one checkpoint as the platoon continues to monitor, and as shifts end and soldiers turn over, the audio data keeps a running total of the approximate numbers of small and large vehicles that continue to approach the checkpoint.

Long term analysis conducted by the S2 suggests that the ratio of large trucks to cars has risen dramatically. While this is something the soldiers at the checkpoint should be aware of, the change happened gradually over the past 5 hours and through a shift change. This information is relayed to the checkpoint so they can be more vigilant about the types and possible intent of vehicles they're encountering.

With this information, soldiers begin spending more time checking vehicles, and interpreters are talking to drivers and passengers. At one point, while a truck is being checked, 4 men get out of another truck about 50 yards away and walk in the opposite direction. When this truck arrives at the checkpoint, a thorough search is conducted, and several explosives are found under the drivers and passengers seats, as well as a few guns and an RPG in the bed of the truck. Soldiers detained the man for questioning and confiscated the explosives.

Aside from noting car to truck ratio, other uses of audio engine signatures could be to determine the rate of cars going through the checkpoint over time, estimate the number of certain vehicles that are approaching, vehicle analysis such as chemical sniffers or misloaded vehicles, vehicle / person classification, or just to assess the overall traffic of all vehicles as it changes over long periods of time.

APPENDIX E

FULL TEXT OF RECONNAISSANCE SCENARIO EPISODE

Because of the impending evacuation operation, the commander decides to patrol the area reported to be used as a base of operations by militants. It is assessed that the buildings in this area should be relatively unused by civilians during late evenings and nights. The patrol is tasked with emplacing hidden sensors in some buildings that are assessed to be militant safe houses. The team places a few sensors near building entrance areas.

Once emplaced, the information from the sensors is relayed to the S2, and analysts monitor the audio signatures of people entering and leaving the different buildings. Algorithms are adjusted determine the relative sound signature changes which could be indicative of a changing makeup in the population. For instance, a significant shift in audio signature towards lower frequencies could indicate a higher than normal presence of military-age males. Identification of changes in group composition and activity may indicate changing threat activity. As changes occur, audio snippets are available for analysts to listen while attempting to ascertain more definitive information. While monitoring the pattern of signatures, analysts can observe the sensor reports in compressed time. This enables review of many hours of data over a comparatively small scale, which allows patterns (and therefore anomalies) to emerge.

While monitoring these signatures, analysts notice that for one particular building, there appears to be a significant human presence in the late hours of the evening. Listening to audio clips they determine the makeup to be largely male. Since this does not match the patterns found for any other building, it seems very suspicious. The next day, a patrol is sent to collect some of the other sensor units and redeploy them in this building in an attempt to get a more robust picture of the nature of activities taking place after hours.

Rather than being used simply for entrance and audio detection, these sensors must now operate as an integrated (and closed) network to help track movement within the building as well as capture audio clips. This network would be a smaller version of the same one set up as a partial perimeter around the embassy and helipad. Similar controls are available to the S2 to monitor this network. The data indicates that men enter the building and spend most of their time in the basement before leaving a couple of hours later. During the next day, a patrol is sent to investigate.

Inspection of the basement reveals local area maps and other papers with writing on them. They also find supplies which could be used to create explosives although there is no direct indication that anything has been constructed. A follow-up search operation is then planned for the following night.

When the patrol returns the following evening, the men do not show up. After waiting until 03:30, the patrol enters the building and finds all the maps, papers, and materials gone. They also notice that a few of the sensor units are missing, indicating the men were aware they were being watched and have relocated.

APPENDIX F

FULL TEXT OF EVACUATION SCENARIO EPISODE

As the first American citizens begin arriving at the embassy, U.S. troops prepare for increased evacuee flow. Traffic patterns on the streets leading to the embassy are being monitored and mediated through the checkpoint. Americans are ushered into the embassy, and flown by helicopter to the nearby airport where they will await transfer out of the area.

Traffic in and around the embassy increases gradually but steadily as the U.S. citizens congregate and are directed where to go. Analysis of data from the sensors at the checkpoint coupled with reports from patrols indicates that over the last 24-hour period there has been very little suspicious activity. It is believed that the enemy has abandoned the use of large vehicles because of the checkpoints and their tendency to be searched. By the time this new trend was noticed, almost every truck and large van was stopped and searched. Because the area is becoming more and more crowded the S2 and analysts are constantly monitoring the sensor readouts, looking for something out of the ordinary.

One afternoon, at a time when traffic is particularly heavy, an analyst notices interesting sensor reporting. At approximately the same time it appears that 3 of the checkpoints are registering vehicles with almost an identical audio signature. His thought is that perhaps the enemy is trying to smuggle hazardous materials at multiple locations simultaneously. The S2 relays this information to each of the checkpoints and they begin searching every vehicle very thoroughly. In one sedan, some plastic grocery bags containing gunpowder are found. The material is reported back to the headquarters. At another checkpoint, some plastic casings were found that could be used to make explosives.

Realizing that the enemy may have adapted to the security of the general area around the embassy, S2 recommends that the currently deployed sensors be redeployed into areas that he has identified as new possible locations of infiltration.

One night several sensors detect a possible intrusion. Listening to the accompanying audio clip, the analyst can make out what appears to be a group of males engaged in a non-English conversation. A translator is brought in and can make out only a few words due to the low bandwidth and interference of ambient noise. While the analyst keeps monitoring the sensors, all of a sudden two of them stop responding altogether. Because of the normally low traffic at this time of night, a reaction force is sent to the area. By the time they arrive no persons are found in the immediate area but they see that one sensor has been destroyed and another appears to be missing.

Back at the Embassy headquarters another sensor array detects movement, very similar to the previous one in a nearby area. A review of the audio data reveals that the same group of people are in that area. The S2 contacts the reaction force to alert them about the enemy's new location. They arrive quickly and confront 4 men with partially-completed IEDs. They are apprehended, detained, and questioned. The explosives are confiscated and the area searched for more such threats. Among the confiscated material they find their missing sensor, badly damaged.

APPENDIX G

PROCESS TRACE OF NASA SCENARIO

Stage	Prime (Carrol)			
	Location	Cues	Mindset	Actions
1	His NASA Office	Time of day, schedule reminder	Time for meeting	Left office with coat
2	Offsite Meeting			
3	Offsite Meeting			
4	Offsite Meeting			
5	Offsite Meeting			
6	Offsite Meeting			
7	His NASA Office	Messages count on notices icon	Missed DCI Events	(logged into DCI)
		Login	Wants to know what he missed	Brings up sched
		Schedule	Missed time critical events	Brings up notices
		Notices window	Missed LORC (how?)	Looks for pager
		Pager on desk	Left Pager	SAD

Figure G1: Original NASA Scenario process trace (each page represents a different agent).

Continued

Figure G1 (continued)

Stage	Backup (Dave)			
	Location	Cues	Mindset	Actions
1				
2				
3				
4	His office	visual notification of caution (not seen by Dave)	non dci related tasks (on phone)	
		beep (and red icon not seen by Dave)	computer needs attention and this is more important than the phone call	hangs up phone, looks at CDI GUI, brings up schedule
		schedule changed	needs to fix communications problem	acknowledges responsibility, gets more information about task by bringing up the Notification view
		groups tab	The prime is not available	logs out
5	Enroute to WRS		urgency (bacterial colonies can die quickly)	Drives to water lab
6	WRS	flashing heartbeats	Problem not fixed	logs into 3T system
			Try to fix the problem	Fixes the problem
		smiley faces return	communications are restored	fixes problem
		notice viewer changes	more info on fix - detail	looks at situation viewer (including annotation)
7				

Continued

Figure G1 (continued)

Stage	Coordinator (Pete)			
	Location	Cues	Mindset	Actions
1	His NASA Office		Busy non-DCI tasks – nothing DCI related to do	
2				
3				
4				
5	His NASA Office	DCI Notices	Dave is handling problem in Carrol's absence, he needs to continually monitor his notices	
6				
7				

Continued

Figure G1 (continued)

Stage	Automation (Multiple Agents)		
	Cues	Mindset	Actions
1	no activity on Carrol's machine	Carrol has gone to meeting	- logs Carrol out
2	LORC problem is detected by 3T	a controls event has occurred requiring human intervention (DCI)	Prime's schedule is replanned, forwarded to Ariel agent
	Prime is logged out	contact prime by pager (prime's preference when mobile)	Sent page to prime's pager
	Specified time elapses without acknowledgement by prime	prime not responding	Sends 911 page to prime
3	Specified time for 911 acknowledgement expires	Need to contact backup based on predefined rules	Backup's schedule is changed
4			clock on backup's screen flashes yellow caution symbol
	No response to visual cue	Backup not looking at display	audible beep & yellow caution turns to red
	Backup logged out	Backup is enroute to WRS	
5			
6			
	backup logs in	backup is at WRS	updates backup's schedule
	Comms restored	backup has fixed communication	notice viewer changes
7			

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