VISualization of Threats and Attacks (VISTA) in Urban Environments

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VISualization of Threats and Attacks (VISTA) in Urban Environments. Traditionally, the military intelligence analyst has been able to focus on a known enemy within situations that are relatively comprehensible. Uniforms, military vehicles, equipment, and communications patterns, to name a few, could identify the enemy and help to clarify the situation. The natural terrain shaped maneuvers and gave the analyst a framework to view the battlefield. Predicting the enemy's course of action, while never easy, could at least be attempted using traditional Major Theater of War (MTW) terrain analysis tools.

Today there is a new battlefield and a nontraditional enemy. Although this was true before 11 September 2001, the events of that day have put this challenge at the very center of our national military policy. Intelligence analysts must face an enemy that does not use a standard uniform, does not travel in military vehicles, and does not use the natural terrain exclusively. Many of the battles of today and of the future will be fought in urban environments—populated areas filled with objects constructed by humans.

The complexities of such urban environments create a variety of challenges for the military analyst. These complexities were apparent, for instance, during the summer of 1999 when North Atlantic Treaty Organization (NATO) deployed a multinational military force, known as the Kosovo Force (KFOR), into the city of Pristina, the capital of Kosovo, to bring peace to the warring factions and end ethnic cleansing by the Serb Army. Upon entering the city, KFOR faced a multitude of problems that included, but were not limited to—

- The mass movement of ethnic Albanian and Roma refugees.
- Newly displaced Serb civilians.
- An active international humanitarian community.
- Armed combatants comprised of the Serb military and the Kosovo Liberation Army.

Faced not only with the task of quickly grasping the "on-the-surface" situation, intelligence analysts soon realized they also needed to provide their commanders with an understanding of Pristina's "landscape"; an urban intelligence preparation of the battlefield (IPB) that assessed communications and social networks, the "tempo" of the city, and the major perceptions and predispositions of its inhabitants. While a large volume of information was available to these analysts, trying to understand how seemingly unrelated events might combine to create the next catastrophic event was nearly impossible. For example, how would they assess the return of displaced ethnic Albanian refugees to their homes? Besides ensuring that the combatants were identified and isolated, they needed to consider environmental factors such as weather, available power and drinking water, movement constraints from destroyed roads and emplaced minefields, and the composition and attitudes of the refugee group. Likewise, it would have been problematic to understand the relative impact of inserting friendly forces at various locations. In short, it would have been difficult, if not impossible, for an analyst using the tools available then to fully understand the potential for seemingly unrelated conditions to cascade into significant events.

Much of this problem remains today. What is needed is a system that promotes understanding through visualization and analysis of the sudden, nonlinear, emergent events that characterize complex systems like operations in urban settings. In one sense, the problem is much like trying to understand and visualize severe weather events such as tornadoes that depend on a myriad of interrelated factors. Although the weather remains a complex problem, it is increasingly possible to predict the likelihood of a tornado within a certain time and vicinity. In other words, it is possible to determine when "conditions are right." Similarly, what is needed for military analysts is a system that enables the determination of when "conditions are right" for emerging threats. Given a certain set of conditions–and a way to visualize the consequences of multiple interacting factors–an analyst may be able to "forecast" possible scenarios.

Note, however, that the urban problem differs from the weather problem in at least two important ways. First, unlike the weather, the urban situation can be influenced (for example, by inserting forces in particular locations, the chance of future threats may be altered). Second, the urban situation is purposively dynamic (for instance, the actors are constantly adapting). Over time, the "landscape" of the urban operational setting changes and, consequently, the likelihood that "conditions are right" changes as well. In the KFOR example, some Serb Army garrisons, weapons cache sites, and government municipal buildings have since been taken over by Albanian and United Nations organizations–radically changing the landscape. To cope with this complexity, the analyst needs a tool that enables visualization of potential outcomes given hypothetical conditions and probable changes. One such tool is now under development.

Under an (SBIR) contract with the Army Research Laboratory, Aptima©, Inc., is currently working with the Center for Computational Analysis of Social and Organizational Systems at Carnegie Mellon University to design a prototype tool for VISTA in urban environments. The U.S. Army Battle Laboratory and TRADOC Systems Manager All-Source Analysis System (TSM ASAS), Fort Huachuca, are providing subject matter expertise. Ultimately, the tool promises to facilitate "forecasting" of potential events by enabling exploration by manipulation of conditions. By enabling exploration of various actions and outcomes, the system will allow an analyst to visualize the types of events that are possible, the likelihood of those events given certain conditions, and ways to maximize the likelihood of certain types of outcomes.

The VISTA Model. The VISTA model is based on complex systems theory, sometimes referred to as the science of chaos, which is a perspective for conceptualizing nonlinear dynamical systems.[1] Complex systems are typically characterized by a large number of interacting elements that combine to produce emergent behavior–the behavior is not prescribed ahead of time, but rather, arises from interactions between the system components (self-organization).

Multi-agent models are often used to examine adaptive behavior in complex systems.[2] Multi-agent models represent system components as agents that interact. For instance, in the area of intra- and inter-organizational dynamics it has been found that the coupling of multi-agent models with networks leads to a powerful toolset for growing and analyzing the complex behavior of diverse entities.[3] Using a multi-agent network approach it is possible to describe and predict potential emergent properties for networks of friends and enemies such as those that one is likely to encounter in an urban or counter-terrorism situation.[4]

In particular, the VISTA model rests on a multi-agent network approach[5] that incorporates multiple interacting and adaptive elements (agents) that represent enemy entities and different regions of a given city. Each city sector agent reacts to events depending on its characteristics, history of having been threatened, and its connectivity with other regions. The enemy agents generate threats and respond to the city sectors depending on their characteristics, history, and connectivity to other enemy agents. The model focuses on how these agents, friend and foe, interact and learn. System behavior emerges in a self-organized fashion from this interaction.

Figure 1 shows the conceptual framework for the model, which specifies at a high level how the system works. There are several key components to VISTA:

- A database with background information on historical events related to urban operations (Historical Database). These events will include information on incidents like those in Hue City, Mogadishu, and Kosovo.
- A database containing information on the city being evaluated, both in general and by region or sector within the city (City Database). This will include information such as the size of city, population density, poverty levels, and locations of key infrastructure, based in part on categories of information addressed in items such as FM 3.06, [Urban Operations],[6] and MCIA-1586-005-99, [*Urban Generic Information Requirements Handbook*],[7] This database and the historical database will focus on critical aspects of urban operational environments that can feasibly be captured in the model.
- A database containing information on typical threat and non-threat agent characteristics (Enemy and other Players Database).
- The City Threat Evaluator that judges the likelihood of a threat and its potential severity by relying on data about the city of concern, including items such as the physical, political, economic and demographic layout, as well as social structure characteristics (as captured in the above databases). Similarly, for each sector (region) in the city, the system uses sector level characteristics and threat agent characteristics as captured in the databases. Based on this collective input, the city evaluator uses a multi-agent network engine to predict the potential for threat on each sector by each enemy for different types of threats (for example, bombings, riots, assassinations).
- The Future Event Evaluator that is used to ask "what-if" questions about specific events of interest, either friendly actions such as the movement of troops or aircraft, or possible actions

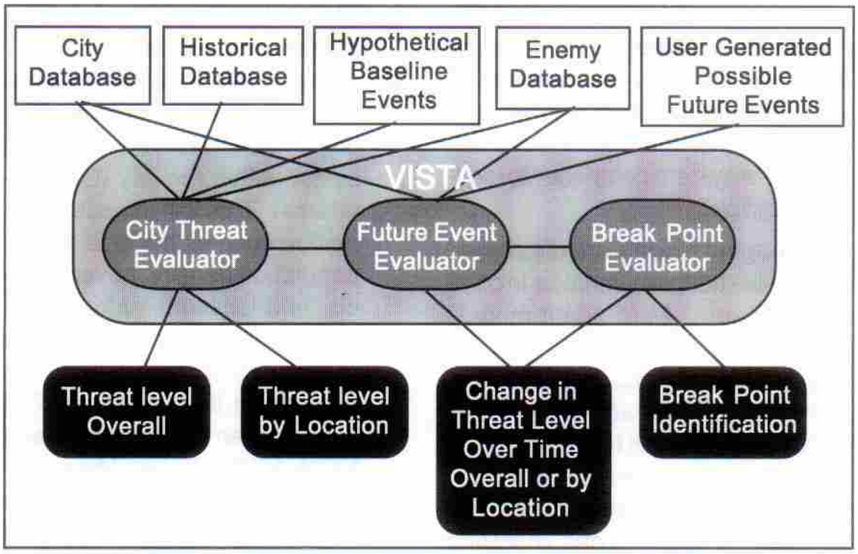

Figure 1. Conceptual framework for the VISTA system.

that are not under friendly control, but are considered likely enough to be of concern (for example, the explosion of a bomb in a populated area). The analyst specifies possible future events, and based on the complex interactions, this module predicts dynamic changes in threat level by time and location, based on the time and location of the events specified by the analyst. The Future Event Evaluator consists of a multi-agent network that uses data on the city in question, a set of hypothetical events, and the historical database to initialize a set of agents who then proceed to act out possible future threat scenarios. Threats and responses to those threats are "grown" as agents, friend and foe, which continue to interact. The model uses an analytic technique to produce results that are statistically analyzed to evaluate the likelihood and severity of threat given a particular scenario, both by geographical location and over time. These agents are dynamic in that they learn, adapt, and respond to other agents. The output of the system reflects the patterns that emerge from the interaction of these agents and represents the likelihood of attacks.

- The Break Point Evaluator will run a variety of "what-if" analyses and determine the relative impact and likelihood of different threats under different response conditions. This aspect of the system will provide the possibility of surprise by threat and weakness by threat mapping, thus creating the ability to systematically explore and represent classes of different actions, events, and outcomes. As a result of this analytic function, the commander's staff will be able to identify and wargame friendly courses of actions (COAs) that best neutralize threat actions and constructively reshape the actions of non-threat players such as international charities.

Ultimately, the system parameters and output will be tuned to data on real-world equivalents to ensure realistic estimates and processes, and the system will be tested against known data from historical events of interest (for example, those in Pristina). Model elements will support a wide range of "what-if" analyses that reflect the complexities of urban environments and that enable forecasting of when "conditions are right" for emerging events.

The VISTA Visualization Tool. The two primary modes of use for the VISTA tool will be data entry and threat analysis. A user might perform data entry when there is a need to add a new city, a need to modify parameters reflecting certain city sectors, or a need to change the overall characteristics of a city. Within threat analysis, the VISTA tool will provide guidance in a variety of ways. First, the analyst will be able to explore the likelihood of threats in various sectors of the city or overall.

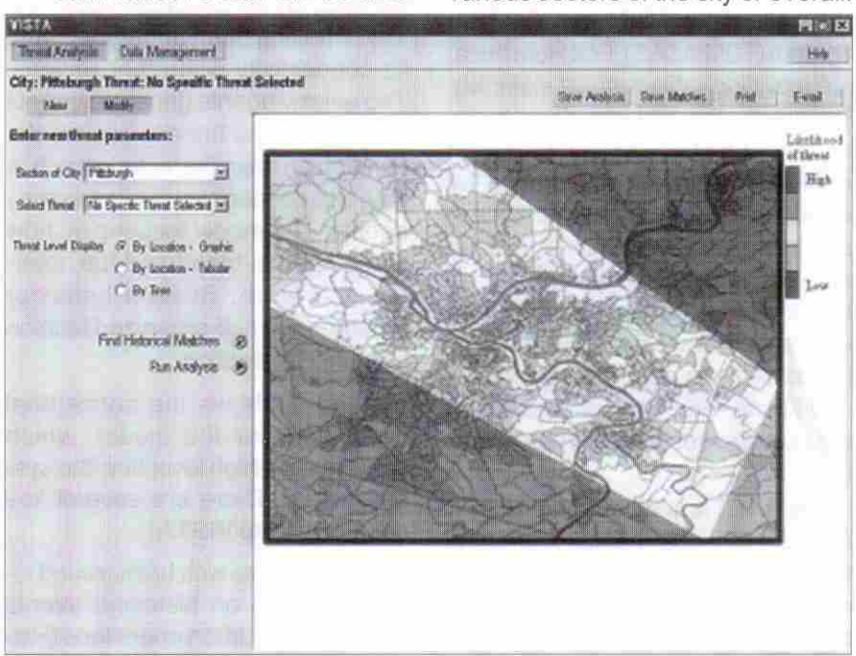

Figure 2. Prototype of the VISTA visualization tool showing threat analysis by city sector where color represents the likelihood of threat.

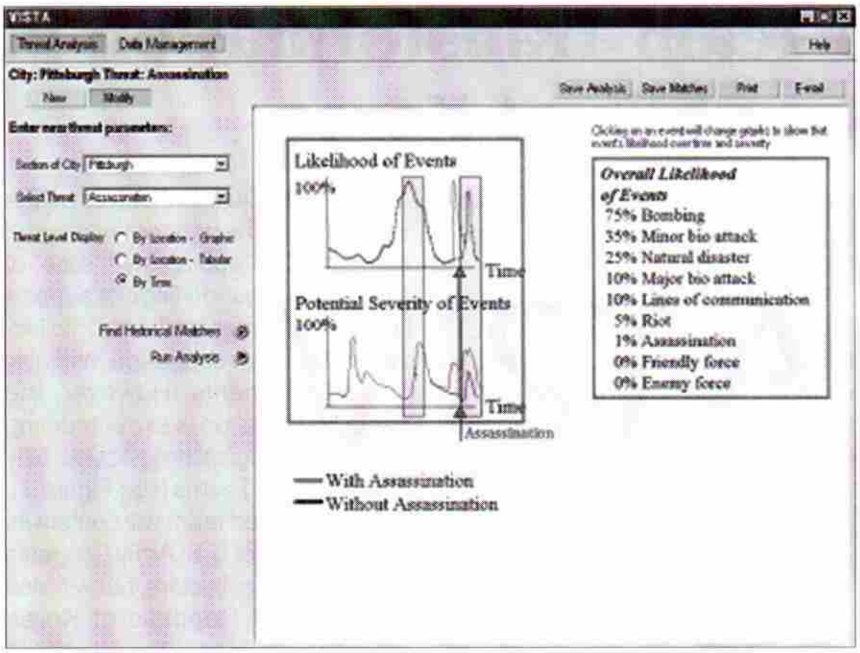

Figure 3. Prototype of the VISTA visualization tool showing threat analysis by time reflecting the consequences of a hypothetical assassination leading to increased threat levels.

Second, it will be possible to use VISTA as a "what-if" decision aid to think through the possible consequences of various types of attacks, actions, or events. This corresponds to interaction with the Future Event Evaluator. Third, with VISTA the user will be able to create an overall map of the relative impact of different types of events (via the Break Point Evaluator).

Taking the example of a threat analysis, Figures 2 and 3 show the types of output and interfaces that will ultimately be available to intelligence analysts using the VISTA tool. In Figure 2 results are displayed graphically by overlaying different colors, corresponding to different threat levels, on the city. In this hypothetical case, the southwest region shows the highest levels of threat, thus supporting rapid identification of problem regions.

Figure 3 shows output over time, presented as a time series (black line). This example illustrates the output of a "what-if" analysis involving a hypothetical assassination leading to shifts and elevations in threat levels over time (the red trace). The system specifies the relative likelihood of different types of events, thus supporting the visualization of a variety of possible outcomes.

Conclusions. VISTA can be thought of as a "social-infrared" system for visualizing the urban battlefield. It is a computational system for forecasting and visualizing the potential threat on complex urban environments. Like night-vision goggles, VISTA will use an underlying model to make visible threats that might otherwise remain hidden by the opacity of the complexity inherent in urban environments. System predictions will reflect the patterns of interaction among the agents in the model that will be based on data about the characteristics of the city sectors and enemies in question. Of course, given the nature of complex systems, the VISTA tool will not enable the precise prediction that a particular type of attack will occur at a certain time and place. Nevertheless, the VISTA system will enable the "forecasting" of conditions and the exploration of possible outcomes given certain events and actions.

TSM ASAS has already begun investigations to determine the appropriateness of integrating a VISTA-like capability as a module within the ASAS-Light, which is a tactical intelligence analysis system that operates on a lightweight, portable workstation. KFOR is currently testing an upgraded ASAS-Light that begins to provide analysts a basic toolset optimized for conducting non-traditional intelligence threat analysis. This initial tool advances IPB and the management of intelligence, security, and recon (ISR) in a stability or support environment. The next step, however, is to leverage COA development models that not only facilitate deeper visual insight but also prompt rapid, decision-focused analysis. Thus, the combination of ASAS-Light and VISTA will result in a powerful and cutting-edge analysis suite that will help analysts to focus collection and track asymmetrical threat factors with greater specificity.

Endnotes

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