Modeling and Simulation Support for Critical Infrastructure Protection [1]

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John Dockery is a senior scientist with a Ph.D. in physics some 40 years ago from Florida State University. His career spans institutional, educational, and governmental service. Although formally retired from federal service, his interest and activity in fundamental investigations remains unabated. What has changed over the decades is the focus of his investigations. Starting with particle physics, he morphed into space science, then operations research, then military problems and more. Now the focus is societal problems to which he brings a strong physical modeling background. Among his career assignments of note were 10 years with the Joint Staff in the Pentagon as an advisor on computers especially those dealing with command and control; and four years at the SHAPE Technical Center in The Hague, Netherlands.

MODELING AND SIMULATION CAN SUPPORT DEVELOPMENT OF NEW KNOWLEDGE FOR CRITICAL INFRASTRUCTURE PROTECTION

Critical infrastructures are embedded in complex societal environments in which many different types of terrorist and other types of threat can expose unknown and unexpected vulnerabilities. It is clear that methods for identifying the emergence of such threats and assessing the capability of existing and envisioned human and physical protective measures to respond to those challenges are urgently needed (Woodcock, 2004a, 2004b). Small, agile, and responsive computer-based models can provide significant insight into the dynamics of the response of protective and restorative systems to hostile attacks and provide at least some of the knowledge needed to identify strengths and weaknesses and develop new tactics, strategies, and policies for threat containment.

In a recent study, a relatively simple epidemic disease model was produced by Woodcock using systems dynamics methods. The model was used to examine the notional effect of the timing and magnitude of public health intervention in response to bio-terrorist actions. Those studies provided a basis for further examination of the safety of the United States' blood supply (Nicogossian, 2004). Recent studies by Dockery have shown that Fuzzy Mathematical methods could provide new insights to support assessment and alerting of terrorist threats to the wider society. Other work has led to the production of a systems dynamics-based model of counter-terrorist actions as well as other model-based facilities that have been used to assess the impact of tactics, strategies, and policies for Afghanistan in 2003, and Iraq in 2004 in exercises held at the Swedish National Defence college in Stockholm, Sweden.

This paper outlines the development and use of model-based computer facilities by Woodcock, Dockery, and their colleagues that have provided, or will provide new knowledge and understanding of critical infrastructure protection, counter-terrorist operations, peace and humanitarian operations, counter-narcotics, and stabilization and reconstruction operations. Research by the author and his colleagues has developed societal dynamics models. Results from this work have provided the basis for the development of new facilities to support informed policy- and decision-making and related activities and development of new insights into the behavior of complex societal systems.

- <u>The Critical Infrastructure Protection Modeling and Analysis (CIPMAS)</u> project is begining under Woodcock's leadership. CIPMAS will provide estimates of the effectiveness of existing and notional critical infrastructure-related activities, policies, and legislation in protecting those structures. CIPMAS could support training and education of business and government leaders.

- <u>A Fuzzy Mathematics Approach to the Study of Terrorist Threats</u> Recent analysis by Dockery has suggested that a Fuzzy Mathematical approach to the analysis of terrorism and terrorist threats might provide significant new insights. These activities will be extended during the CIPMAS project.

- <u>Systems Dynamics-based Model of Counter-Terrorist Operations</u> is based on the Conceptual Model of Counter Terrorist Operations (CMCTO). The systems dymanics-based model can support study of the dynamical consequences of particular terrorist and counter-terrorist actions and policies and development of a systemic approach to identifying and responding to terrorist threats.

- The Strategic Management System (STRATMAS) is being developed in a project funded by the Swedish National Defence College and the United States Joint Staff (J8). It has been used to support a post-conflict stabilization study of Afghanistan in January 2003 and to support *Exercise Iraq Future '05* in April 2004 at the College.

- The Deployable Exercise Support (DEXES) System was developed and used to support at least fourteen United States Southern Command (USSOUTHCOM) multi-national peace and humanitarian operations exercises in South America.

- The Counternarcotics Modeling and Analysis Capability (CMAC) can asses the effectiveness of counter-narcotics force actions on narcotics trafficker air operations. CMAC was used successfully in a major counter-drug exercise for the United States Southern Command (USSOUTHCOM).

A PROTOTYPE CRITICAL INFRASTRUCTURE PROTECTION MODELING AND ANALYSIS SYSTEM (CIPMAS)

The CIPMAS project will commence shortly at George Mason University under the leadership of Woodcock. CIPMAS will use computer-based models to assess the vulnerability of identified critical infrastructures to hostile actions. It will provide estimates of the effectiveness of existing and notional critical infrastructure-related activities, policies, and legislation in protecting those structures. The prototype CIPMAS could support training and education of business and government leaders through studies that use model-based assessments of the effectiveness of existing and proposed security practices to estimate risk and vulnerability.

DEVELOPING AND USING THE PROTOTYPE CIPMAS FACILITY

An overview of the CIPMAS project is shown in Figure 1. Two major phases of activity are planned. The first phase will involve the production and use of time-dependent models of selected critical infrastructure environments and threats to those environments in a series of studies and experiments. The second project phase will use the results of the initial studies and experiments to design, implement, and test a prototype CIPMAS facility that models both the temporal and spatial aspects of those environments and threats.

PHASE 1: PROTOTYPE CIPMAS SYSTEMS DYNAMICS MODELS

The first major phase of project activity will involve enhancement of an existing series of time-dependent critical infrastructure models developed by Dockery (1996 and personal communication, 2003) that modeled virus attacks on computer system capabilities. Dockery has recently used systems dynamics approaches to model the vulnerability of airport security and critical water and electrical power utility infrastructures. Those models have all been implemented in a systems dynamics modeling system called STELLA™ and used in a series of studies that have provided significant new insights into the nature of computer viruses and the vulnerability of computer and other critical infrastructure systems to attack. Dockery will be a member of the CIPMAS Team. The enhanced models will be used in a series of experiments and studies to examine the nature of critical infrastructure environments as well as the threats to those environments, the effectiveness of responses to those threats, and the expected risks created by particular protective policies, protocols, and facilities.

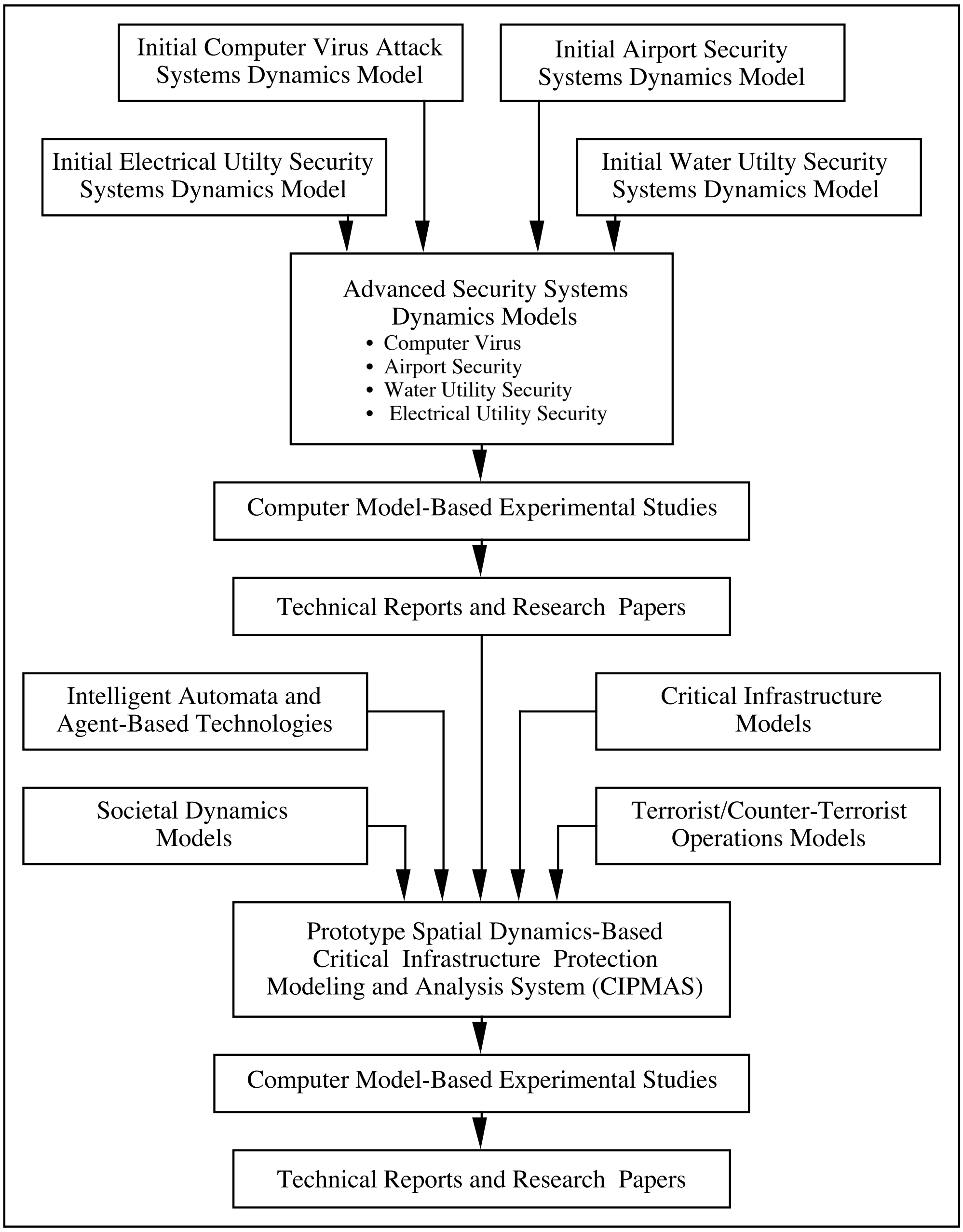

Figure 1: Development of a prototype Critical Infrastructure Protection Modeling and Analysis System will begin with the development and use of systems dynamics models.

PHASE 2: A PROTOTYPE SPATIAL DYNAMICS CIPMAS FACILITY

It is recognized that studies of critical infrastructure require an adequate representation of the geographical location as well as the societal context within which specific critical infrastructure-related entities and processes take place. It is expected that this would be achieved in an extension of the initially-funded CIPMAS study through the use of intelligent automata facilities (developed by Cobb and Woodcock) and appropriate agent-based models. Knowledge gained during the development of the systems dynamics-based models would be used to design the prototype CIPMAS facility. Infrastructure, context, law and regulation and agent/actor models would be developed and used to define the critical infrastructure environment as represented within the prototype CIPMAS

In previous work by Cobb and Woodcock, intelligent automata were designed to use substrate rules (invented by Woodcock to represent the impact of location or context on the automata behavior) to show the impact of terrain on movement, the effect of different population densities on the spread of disease, or the ways that other spatially-distributed properties could influence overall system behavior. A preliminary study carried out some 10 years ago by Cobb and Woodcock used intelligent automata models to represent the attack by insurgents on a high value target protected by a physical security barrier. That and related work will form the basis of the development of a future spatial-dynamics CIPMAS facility.

FUZZY MATHEMATICAL APPROACH TO THE ANALYSIS OF TERRORISM

Dockery has been struck by the absence in all the discussions concerning terrorist activities of any recognition that we are dealing with a subject that is fuzzy in nature. Every thing is treated as if it were a member of a crisp set. He has suggested that it is important to look at the language used in circles dealing with the war on terror.

- Consider production rules. “If the threat level is ORANGE and the supporting data is RECENT, then the threat level is to be taken SERIOUSLY.” This is a fuzzy production rule, not a crisp one. It is no wonder that the areas affected by such an alert have trouble responding.

- Consider the language of estimation. One asks: “What is the *possibility* that an event will occur.” This is the study of possibilities, and not probabilities. We note in passing one major distinction between probability and possibility theory. Whereas probabilities sum to one, possibilities need not.

- The aims of terrorist organizations are couched in fuzzy terms. Thus, they seek the following:

    - Kill people.
    - Horrify viewers.
    - Create chaos.
    - Bring down complex systems.
    - Prevent business and the political process from operating.

If we adopt a fuzzy framework for our analysis, then we are in the newly emergent discipline of approximate reasoning. The foundations of approximate reasoning lie in Brouwerian logic, which is non-distributive. A classical question which Brouwerian logic addresses is as follows: "Are the number of grains of sand on the beach odd or even?"

Once we open the door to fuzzy reasoning other methods of dealing with imprecision present themselves. We might now consider fuzzy automata and fractal measures. The latter may be particularly interesting. In unpublished work, Dockery and Woodcock have investigated the fractal measure of small, but highly cohesive groups. We believe that such groups although vanishingly small in number may, nonetheless, appear to be influential because of high fractal values in a properly chosen dimension or structure. As for fuzzy automata, we propose to investigate the result of having automata rules couched in fuzzy terms, for example, if surrounding cells *almost always* exhibit some feature.

Fractal Mathematics- and Fuzzy Logic-based methods and well as the concept of Fractal Organizational Structures will be used during the CIPMAS project. It is expected that these methods will provide unique new insights into the nature of terrorist and other threats as well as the impact of the warnings used to alert the wider public to the possibility of future terrorist actions. It is possible that results obtained from those studies might provide the basis for identifying where changes concerning the policies that define the conditions under which threat warning are issued might be made.

A SYSTEMS DYNAMICS-BASED MODEL OF COUNTER-TERRORIST OPERATIONS

A model of counter-terrorist operations based on systems dynamics principles has been developed, during a project funded by the US National Defense University, by Woodcock at George Mason University. The model provides a representation of the interaction of a significant number of the factors at work in environments where terrorist attacks and counter-terrorist actions can take place (Figure 2). That model is based on the Conceptual Model of Counter Terrorist Operations (CMCTO) built by Davis, Woodcock, and their colleagues at George Mason University. The systems dynamics model provides a facility for studying the dynamical consequences of the adoption of particular terrorist and counter-terrorist actions and policies and insight into the development of a systemic approach to identifying and responding to terrorist threats.

The Systems Dynamics-based model is a preliminary model. Validation and verification of model processes and parameter and coefficient values by appropriate subject matter experts would be necessary before the model could be used to support actual operations (Figure 2). The systems dynamics model has provided a mathematical representation of many of the key factors considered to be at work in the terrorist/counter-terrorist environment. The model permits its users to undertake a series of studies to examine what might happen under particular user-defined conditions if at least some of the actions defined in the CMCTO were undertaken.

It is hoped that extensions of the CMCTO and enhancement of the systems dynamics model could be undertaken in the near future. In particular, it is believed that the systems dynamics model has provided an appropriately detailed and integrated facility for the comprehensive study of the terrorist/counter-terrorist environment and of the societal factors that cause disaffection, radicalization, and terrorist actions, on the one hand, and those that lead to affection, societal integration, and the undertaking of counter-terrorist actions, on the other. Further development and enhancement of both the CMCTO and the systems dynamics models are contemplated with great interest.

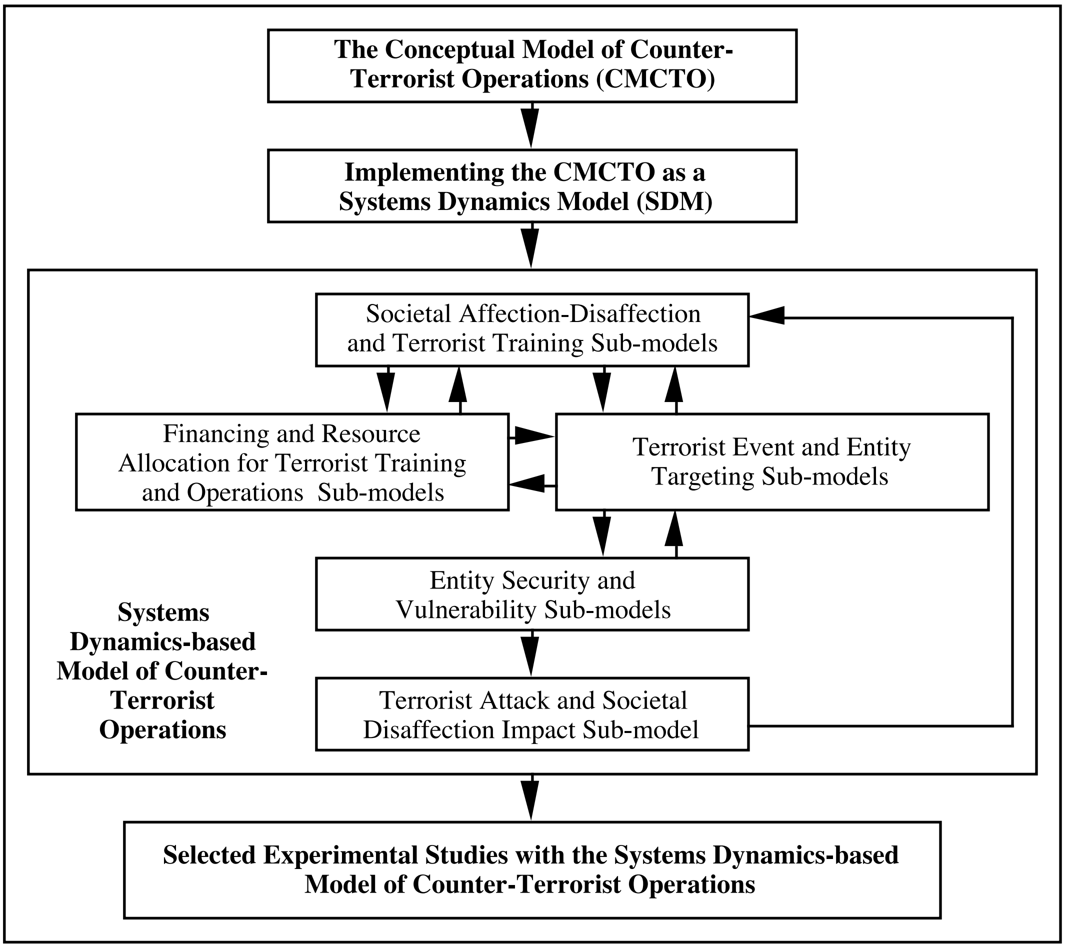

Figure 2: Implementing and using the CMCTO as a Systems Dynamics Model.

Systems dynamics model development has involved the production of a series of sub-models that capture the essence of the environment within which terrorist and cvounter-terrorist activities can take place and their linking to form an overall model. STELLA™, a commercial off-the-shelf systerms dynamics software modeling facility has been used for model implementation. Results of a selected series of computer experiments with the systemd dynamics model are described and suggestions are made concerning future model-development activities. Sub-models developed during production of the overall systems dynamics models include the following:

- Societal Affection-Disaffection and Terrorist Training Sub-models describe the process of societal disaffection that creates individuals who would be available for recruitment as terrorists, who could be provided with terrorist training, or as radical leaders, who could finance terrorist training and operations. These sub-models also represent the processes of basic and advanced terorist training for mass, bio-, explosives, suicide bombing, and small arms terrorist acts.

- Financing and Resource Allocation for Terrorist Training and Operations Sub-models describe the generation of financial resources by the actions of redicalized leaders in a country of interest as well as by external leaders. The sub-models also descibe the process of resource allocation to basic and advanced training as well as for the operational support of mass, bio-, explosives, suicide bombing, and small arms terrorist acts.

- Terrorist Event and Entity Targeting Sub-models describe the generation of potential notional terrorist actions in the areas of mass, bio-, explosives, suicide bombing, and small arms attacks. Undertaking actual notional actions within the model depends on the availability of appropriately-trained individuals to carry out those actions.

- Entity Security and Vulnerability Sub-models describe the effect of the balance of countter-terrorist investment in providing security for notional entities and the actions of terrorist investment in undermining that security. Mass, bio-, explosives, suicide bombing, and small arms terrorist attacks on notional entities depend on the availibility of trained terrorists and the relative vulnerability of the intended target(s). Some modeled attacks may fail while others may succeed. Successful attacks are followed by a transient boost in security funding.

- Terrorist Attack and Societal Disaffection Impact Sub-models are based on the assumption that the second and subsequent attack on an entity would cause an increase in societal disaffection due to the perceived failure of the government to provide adequate protection. Mitigating actions can off-set some of that disaffection.

The systems dynamics-based model provides a series of model components representing the impact of counter-terrorist actions on the abilities of terrorists to attack notional entities. These include facilities for seizing terrorist financial assets, neutralizing the impact of external leaders and their funding sources, disruption of terrorist training and operational capabilities, and actions aimed at reducing the initial levels of disaffection within a society and mitigating the impact of terrorist actions in creating new levels of disaffection.

THE STRATEGIC MANAGEMENT SYSTEM (STRATMAS)

The Strategic Management System (STRATMAS) is being developed for the Swedish National Defence College and the United States Joint Staff (J8) by a small international team led by Woodcock. STRATMAS was used to support a post-conflict stabilization study of Afghanistan at the Swedish National Defence College, Stockholm, Sweden in January 2003. STRATMAS was used to support *Exercise Iraq Future '05* that was held at the Swedish National Defence College at the end of April 2004.

During the Afghanistan study in 2003, STRATMAS provided a realistic representation of a notional societal environment in Afghanistan within which peace and humanitarian operations could take place. During these activities STRATMAS-generated societal data were displayed in both map-based and textual formats and used to set the scene for the study participants and to provide a basis for assessing the effectiveness of their actions that involved planning for the deployment of military forces and civilian entities to support post-conflict stabilization. The Study took place in the Aquarium facility, the Swedish National Command and Control and Crisis Management Testbed, at the College under the direction of Anders Christensson, Technical Manager for both STRATMAS and Aquarium projects (Figure 3).

Figure 3: The Aquarium facility at the Swedish National Defence College was the site of the Post-Conflict Stabilization Study of Afghanistan in which STRATMAS supported analysis, assessment, and planning activities for military forces and civilian entities.

Exercise Iraq Future ’05 also took place at the Swedish National Defence College in Stockholm and provided an environment for over 100 middle rank international military officers to develop military and insurgent scenarios in order to assess the impact of possible future actions by modeled military and insurgent forces in Iraq. The effectiveness of a series of plans developed during the exercise was assessed with the aid of the STRATMAS facility and reported back to the exercise participants after the exercise had been completed.

Activities during the studies in January 2003 and April 2004 at the National Defence College in Stockholm clearly showed that STRATMAS permitted development of a very significant understanding of the problems associated with post-conflict stabilization in Afghanistan and future activities in Iraq. Development of that understanding was greatly enhanced by the fact that the study took place in the Aquarium facility. Taken together, STRATMAS implemented within the Aquarium, provides a unique and proven support capability for studies and exercises involving post-conflict stabilization and related activities. STRATMAS has been designated by the Swedish authorities as the software 'center of gravity' for future development of the Aquarium.

THE DEPLOYABLE EXERCISE SUPPORT (DEXES) SYSTEM

The Deployable Exercise Support (DEXES) system was designed to support bilingual international training exercises in military operations other than war, civil affairs, peace operations, and humanitarian and disaster relief-related activities for the United States Southern Command (USSOUTHCOM). Woodcock was the first Project Director for DEXES and designer of the system with Loren Cobb. The DEXES software facility was implemented by Cobb.

The DEXES system provides dynamical representations of societal behavior and of the impact of external and internal agents on such behavior. Map and chart displays provide the DEXES user with access to the time- and space-dependent changes in societal behavior generated by pre-programmed and user-initiated events that can guide the future actions and behavior of the exercise participants (Figure 4).

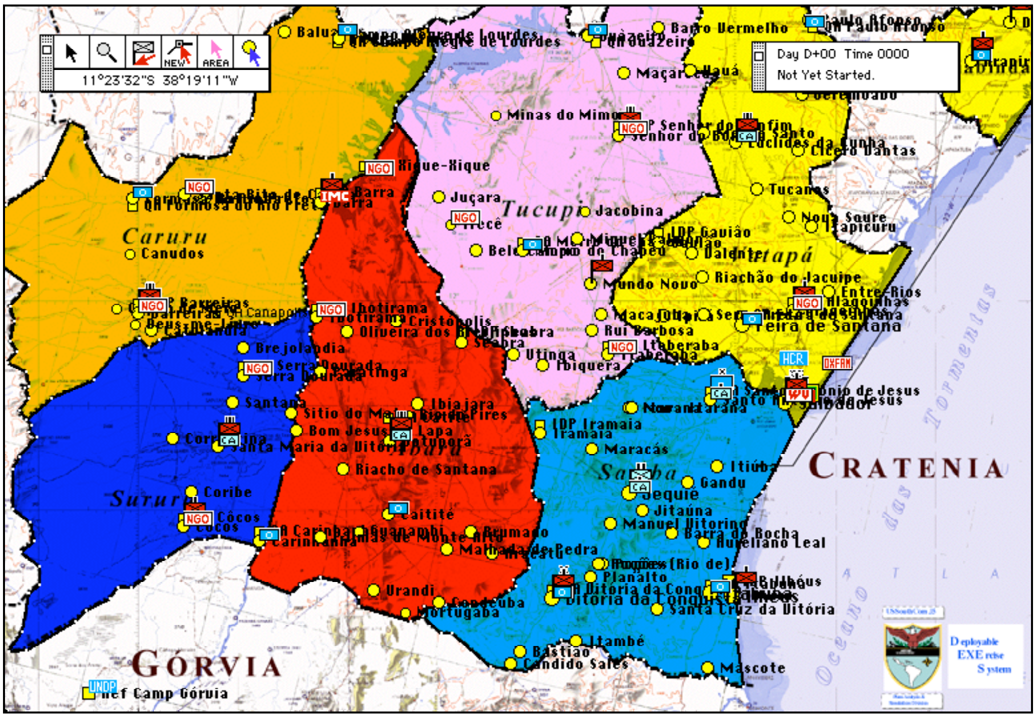

Figure 4: The DEXES map-based graphical information system assists in situation assessment and the command and control of military, governmental, and NGO units.

By virtue of its small size and streamlined design, DEXES can be rapidly deployed in either analytical or training contexts anywhere in the world with minimal cost and support overhead. By 2003 the DEXES system had been used in some fourteen multinational exercises sponsored by USSOUTHCOM and held in South and Central America.

DEXES PROVIDES NEW FACILITIES FOR EXERCISE SUPPORT

In recent conflict environments many military actions are taken during or in the aftermath of civil wars, in which civilian ethnic (or religious) considerations drive both national policy and military action. International peacekeeping operations simply cannot be pursued without knowledge of the societal dynamics that created the conflict in the first place, and a nation cannot be rebuilt without knowledge of how societies actually work. Therefore, we have a need for military training simulations that include, as a vital component, a reasonably complete and accurate model of societal dynamics. DEXES was intended as the first attempt to create such a civil-military training environment.

The Deployable Exercise Support (DEXES) system is a mature facility. DEXES has been used in a significant number of multinational exercises to simulate societal responses to the actions of notional military and civilian players in either scripted or free-play wargame environments. DEXES has been designed to work with scenarios that represent complex social, political, economic, and medical problems that can be expected to occur in the future. Additional challenges to the international community to provide support to peace and humanitarian operations will be created by the emergence of new conflict areas. These challenges will create new requirements for the education and training of both civilian and military personnel and for new types of analytic facilities to support existing and new types of multi-national operations.

USING DEXES FOR EXERCISE SUPPORT

The DEXES system consists of a series of linked models of societal dynamical processes in which behavior is described in terms of the time- and space-dependent variation in the values of the state variables associated with the system. Pre-programmed and user-defined inputs can generate changes in the output of the societal models and such changes can be displayed an specialized maps and in a series of time series and histogram charts. The DEXES system was used to support the FU-SOUTHAM-97 exercise and selected results of this use are presented below. The FU-SOUTHAM-97 exercise was designed as a multinational peace and humanitarian operations exercise involving military units primarily from Brazil, Argentina, Uruguay, Paraguay, Bolivia, and the United States, with contributions from other nations.

The exercise involved the notional deployment of a United Nations sponsored multinational force (UNAFORCRA) to the fictitious country of Cratenia. The mission of that force was to stabilize the political, military, and humanitarian conditions. These activities would provide support for the development of democratic processes and permit the holding of a presidential election prior to the redeployment of UNAFORCRA from Cratenia. Models of the political, public opinion, medical, economic, conflict, and other processes at work in Cratenia were developed within the DEXES system. This model-based system was used to support the activities of the exercise participants. DEXES provides its users with access to small and large scale maps of the operational area for exercises. A portion of a sample small-scale map of a region of Brazil was redrawn to represent the notional country of Cretania for the FU-SOUTHAM-97 exercise and is shown in Figure 4. The DEXES map uses icons to represent cities, displaced person camps, military units, governmental units, non-governmental units, areas of operation, and circles of entity influence.

Use of the DEXES system in an exercise begins with scenario design, in which the training goals of the exercise are specified and activities identified and developed that will permit the achievement of these training goals. In a typical DEXES-based exercise training activities take place during several representative days selected from a much longer notional deployment of an in-country military and civilian peace and humanitarian operation. Role-playing exercise activities might occur on day D+25 or twenty-five days after force deployment, for example. At the end of the exercise day, the participants would be informed that the next day involving activities that were assumed to take place on D+53, for example. The participants would then be asked what actions they would take during that interval, and those actions would be programmed into the DEXES model system. DEXES would then be used to calculate the changes in societal conditions reflected in the changes in the values of the DEXES state variables that actually took place between D+25 and D+53. At the start of the next day (in this sample case, exercise day D+53), the participants could receive a briefing and other information on the new conditions. This would provide the basis for the next day of role-playing activity, and so on.

The DEXES system provides its users with access to societal data showing the regional patterns of variation of the state variables as a function for the six areas of military responsibility (In the exercise in Brazil, there were as follows. Bolivia: BOLBAT; Argentina: ARGBAT; Brazil: BRABAT; Uruguay: URUBAT; United States: USABAT; and Paraguay: PARBAT) as well as for the external refugee population, and the whole country of Cratenia. The following brief discussion of these and other societal data provides an insight into the sample use of model-generated information on Food Deprivation (Figure 5) during the exercise.

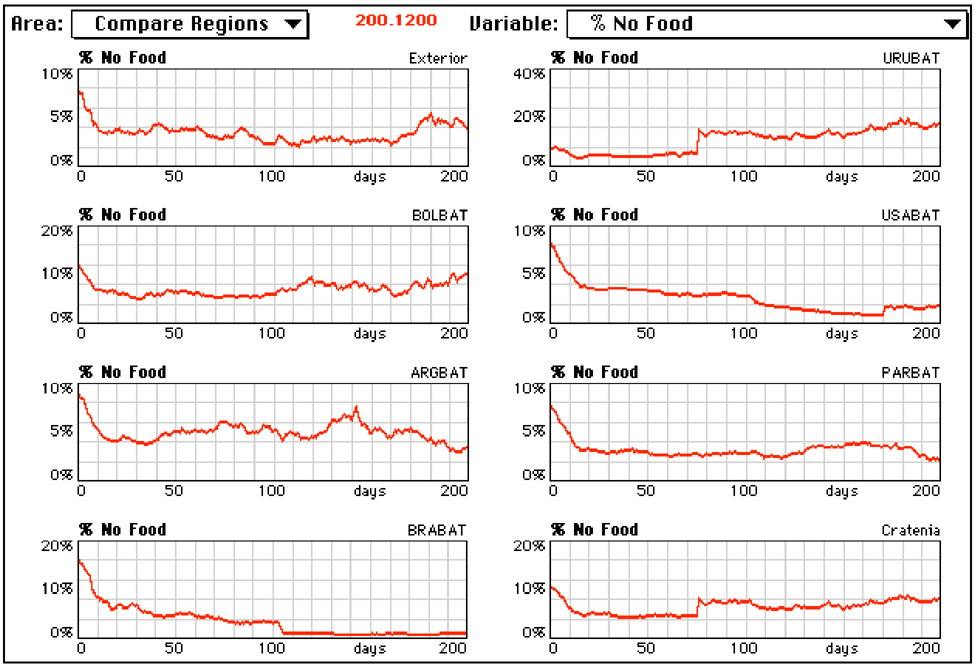

Figure 5: DEXES-based calculations of the regional variation in the levels of food deprivation from exercise day D to D+200.

The calculated variations in the percentage of individuals without food are shown in Figure 5. One of the most significant features of these charts is the sudden large increase at approximately D+75 to some 20 per cent in the number of people in the URUBAT area who are without food supplies. During the earlier exercise activities, an event occurred where civilian entities involved in providing humanitarian relief in that area were assaulted and several individuals were injured. When asked by the military command entities in the Civil-Military Operations Center (CMOC), the civilian role players replied that they would only provide the requested services if properly protected by the military force. The UNAFORCRA Force Commander in role-playing refused to provide such support, and the civilians refused to provide the requested relief services. The level of food deprivation in the URUBAT area generally continued to increase throughout the remainder of the exercise as a consequence. By contrast, civilian actions in the USABAT area led to a significant decrease in the level of food deprivation, for example.

THE COUNTERNARCOTICS MODELING AND ANALYSIS CAPABILITY (CMAC) SYSTEM

In the early 1990s, the United States was involved in a range of counternarcotics operations including air operations against narcotics traffickers in conjunction with several South American governments. A series of counter-drug training exercises were undertaken in order to support the training needed for such operations. One of these exercises, the CMASS-V exercise at the Joint Warfare Center in Florida, used a software system called the Counternarcotics Modeling and Analysis Capability (CMAC) developed by Cobb and Woodcock. The system assisted training in command and control planning and decision-making and in assessment of the impact of counternarcotics radar surveillance and air operations in the drug war to support the counter-drug mission of the United States Southern Command (USSOUTHCOM) (Woodcock and Cobb, 1994) (Figure 6).

Prior to the CMASS V exercise, the Los Alamos National Laboratory (LANL) in Los Alamos New Mexico was developing the *Transport of Illicit Products Scheduler (TIPS)* to generate representative flight schedules for narcotics trafficker aircraft. The Naval Air Warfare Center (NAWC) in Warminster, Pennsylvania, was developing the *Counter-Drug Surveillance Intercept Coverage (CDSIC)* model. However, no way existed to compute the interaction of narcotics trafficker flights (generated by the TIPS model) and counternarcotics activities (generated by the CDSIC model).

The Counternarcotics Modeling and Analysis Capability system was designed and implemented to fill that gap. The CMAC system provided models representing the overall flight process including calculations of range based on prevailing fuel levels and the need for national airforce planes to avoid crossing international boundaries without permission. Interceptors would not be launched if they could catch the target plane based on distance and relative maximum speed calculations, for example. CMAC used data from the TIPS and CDSIC models to calculate the impact of different counternarcotics force and narcotics trafficker strategies and tactics. Results of these calculations were used to provide command and control guidance for selected exercise participants. It should be pointed out, however, that all data presented below are purely notional and should not be interpreted in any way as representing the results of any actual counter-drug air operations.

Figure 6 shows the deployment of notional counter-drug air and ground- and air-based radar assets in response to the challenge of notional illicit drug-trafficker air operations over a 10-day period. The Figure uses histogram displays to show the pattern of narcotics trafficker flights; the number of flights detected as well as the number intercepted, diverted, and other outcomes. Also displayed are the interceptor flights requested and actually launched due to operational considerations.

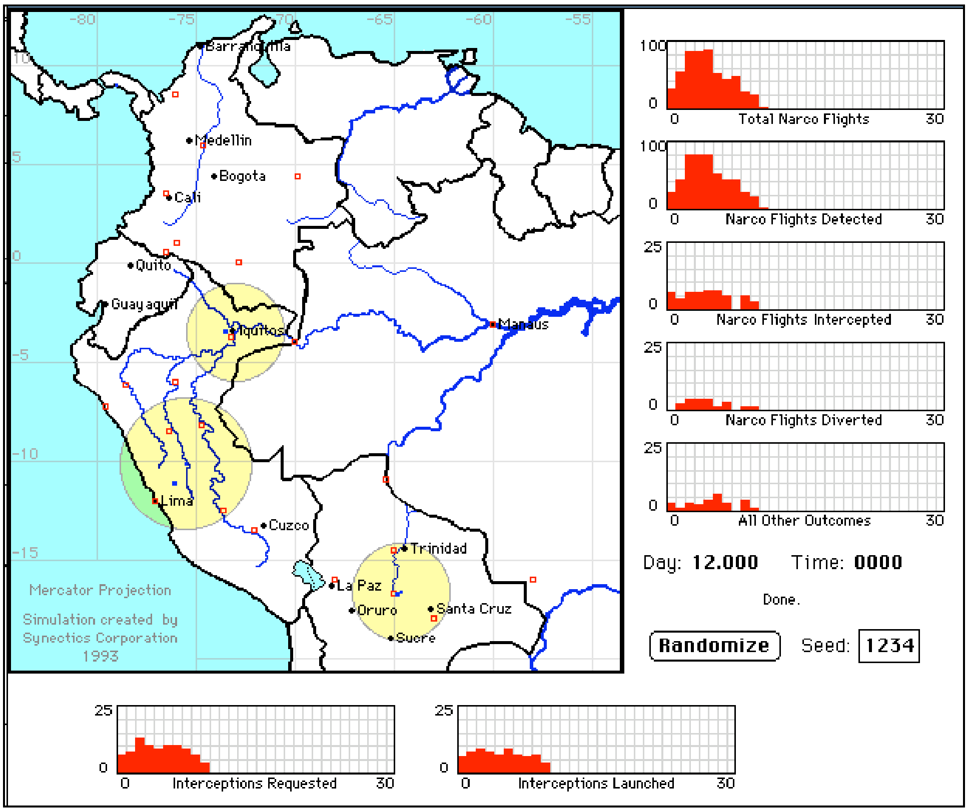

Figure 6: The Counternarcotics Modeling and Analysis Capability (CMAC) facility can compute the outcome of counternarcotics air operations and narcotics trafficker activities (after: Woodcock and Cobb, 1994).

SUMMARY

This paper has outlined some of the research projects undertaken by Woodcock and Dockery and their colleagues to provide models of complex societal environments within which critical infrastructure protection, counter-terrorist, post conflict stabilization, peace operations, humanitarian assistance and disaster relief, and counter-narcotics operations can take place. This work has provided a firm foundation for development of rapid response capabilities to support operations appropriate levels of validation and verification have taken place.

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