Modeling the Governance and Stability of Political Dynamical Systems

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Loren Cobb trained in mathematical sociology at Cornell University, and pursued post-doctoral studies in psychiatric epidemiology at the University of South Florida. His mathematical work in statistical theory for nonlinear systems earned entries in the Encyclopedia of Statistical Sciences and Kendall's Advanced Theory of Statistics. In a 30-year career as an applied mathematician, he has taught and guided Ph.D. dissertations in a dozen different disciplines, and has created models in areas ranging from tumor growth and pharmacokinetics to perception and artificial intelligence. He is the author of three computer languages and holds a US software patent. Now an independent international consultant, he creates civil-military models of societies in severe distress, up to and including civil war, epidemics, revolutions, and natural disasters.

MEETING THE NEW AND EMERGING CHALLENGES TO GOVERNANCE AND STABILITY

New and emerging threats to governance and stability have created the need for new tools and methods to meet those challenges and to provide governments and other entities with the ability to function in changed and difficult circumstances. These threats, which include the widening spectrum of conflict, new terrorist challenges, biological and chemical threats, and the need for military forces to participate in peace, humanitarian, and other types of operation, have created the need for new types of co-operative policy-making and decision-support facilities.

Furthermore, the events of September 11 2001 in the United States and their echo in Afghanistan, Iraq, and elsewhere have demonstrated the need for an informed understanding of the causes of local events and their global consequences. Development of such an understanding demands the production and use of new types of facilities for the dynamic integration and assessment of both military and civilian information that elucidate ongoing behavior and identify beneficial courses of action. The facilities must also permit informed intervention and control in ways that can affect outcomes for the benefit of friendly forces and nations and the disadvantage of others.

Governance implies the need for and existence of some form of command and control mechanisms involving feed-forward and feed-back processes. Stability suggests the possible existence of conditions under which the forces at work in a society achieve some form of balance. The eighth Cornwallis workshop concentrated on developing an enhanced understanding of the nature and role of governance in achieving societal stability. This paper describes how model-based cooperative command and control and crisis management facilities can provide support to those processes (Figure 1).

On-going work at the Swedish National Defence College has produced and is enhancing the Aquarium, the Swedish National Command and Control Research and Development test bed. On-going Aquarium-related activities are being supported by

1. Development of new network concepts for operational staff and decision processes.

2. Formal meeting analysis.

3. Implementation of Visual Interactive Language (VIL) concepts.

4. Production of advanced models and simulations.

These activities will facilitate staff process by the development of new methods for the presentation, manipulation, and analyses of data and the development of new levels of understanding. Governance and Stability can be supported by societal dynamics model-based cooperative command and control and crisis management facilities. Societal dynamics models provide representations of reality and can possess Structural, Time-dependent, Time- and Space-dependent, Statistical, and Evolutionary components. Computer experiments with societal dynamics models can increase understanding of the dynamics of systems and situations of interest.

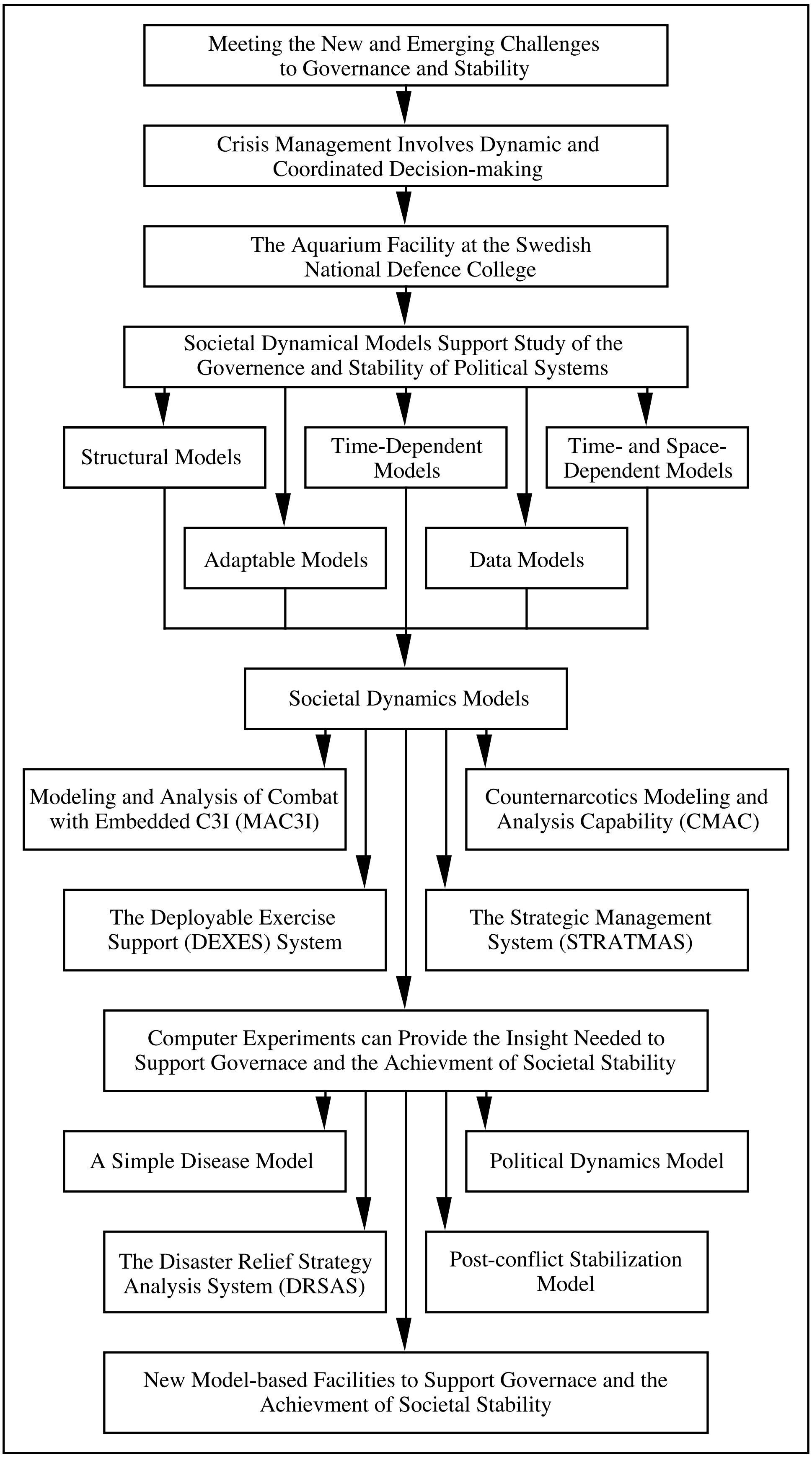

Figure 1: Meeting the Challenges to Governance and Stability by developing and using model-based facilities for analysis, assessment, and planning.

To summarize: new command and control and crisis management procedures involving effective collaborative environments and Visual Interactive Languages (VIL) are providing new facilities to support governance and stability. New societal dynamics models are providing representations of the environments within which conflict, complex societal emergencies (CSEs), and peace, humanitarian and other types of operation can take place. New prototype model-based planning, training, and operational facilities based on societal dynamics models are being produced to support development of a new understanding of the nature of the governance process and of the conditions needed to achieve stability.

CRISIS MANAGEMENT INVOLVES DYNAMIC DECISION-MAKING

Operational command and control involves activities that are aimed at providing sufficiently rapid assessments and decision-making activities that create advantages for friendly forces and disadvantages for hostile forces (Figure 2). The time involved in holding meetings and reporting the results of those meetings from one echelon or level in an organisational hierarchy to other levels in the hierarchy can create significant time delays. Those delays can create a disparity in perception of the operational environment by command-level entities removed from that environment.

The delay in the collection and transmission of information from subordinate to command-level entities and the subsequent generation of orders and other responses may result in the issuing of instructions that are no longer relevant. These statements describe situations that have been largely recognised and are in course of rectification, at least within US and NATO force structures – hence such innovations as “sensor-to-shooter” which bypass the decision-making loop altogether. Speeding up the overall decision cycle process by facilitating data collection and the overall staff processes can provide significant advantages by creating more integrated functional and coordinated command processes.

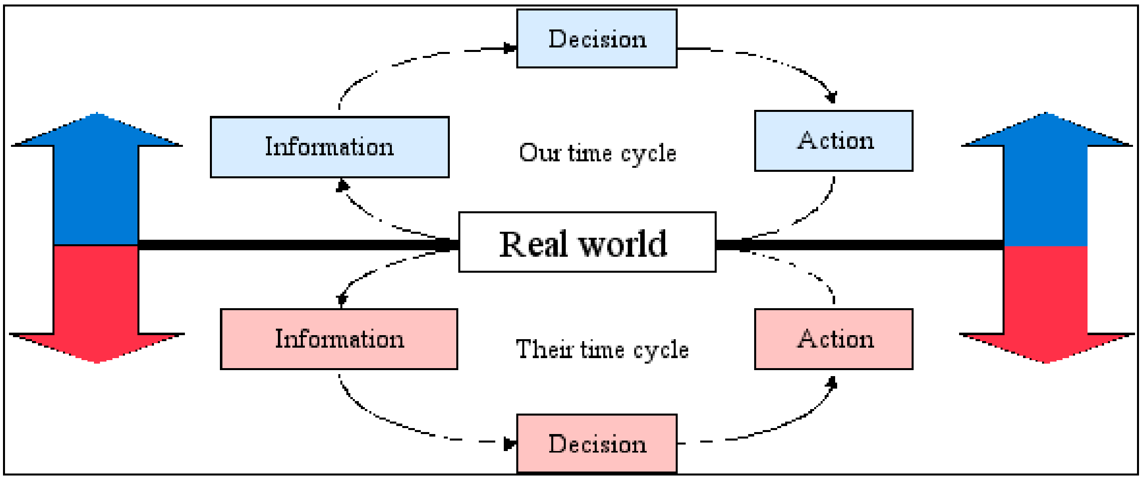

Figure 2: Validated models can support the development of facilities for rapid situation assessment and proactive command and control and crisis management.

Significant advantages will also arise when one side is able to undertake the processes of situation assessment and decision-making more rapidly than the other side. Development of appropriately validated models of the combat environment can support proactive decision-making and crisis management activities by permitting some form of look-ahead estimation of possible courses of action. Such activities can be supported by the development of new facilities for collective assessment and decision-making in a networked environment. Those models could also be used to support a range of management activities involving planning, procurement, deployment, and requirements analysis. These matters are being addressed in research being undertaken in support of development of the Aquarium facility.

NEW NETWORK STRUCTURE MODELS ARE NEEDED

Rapidly changing combat environments demand the active integration and full and timely participation of all military command levels in the overall effort. This has created the need to extend the original 7-layer Open System Interconnected (OSI) network communication model defined by rules that Zimmerman (1980) defined. The OSI structure is based on the assumption of links between single computers and may not be appropriate for the new operational environments faced by Joint Task Forces and Component Commanders. However, Hitchins has pointed out that Level 3, Network, where CCITT X-25 sits, is based on the need to network an unlimited number of processors. All layers above 3 assume multiple processors. Applications, Level 7, presumes a multiplicity of processors, possibly all geographically remote, all working together in support of a networked application.

13. Layer 13: Context and Culture-dependent Issues
12. Layer 12: Strategic, Operational, and Tactical Functions.
11. Layer 11: Decision Support Processes
10. Layer 10: Formal Meetings
9. Layer 9: A visual interactive notation or language system
8. Layer 8: Presentation and manipulation methods for groups.
7. Layer 7: Application
6. Layer 6: Presentation
5. Layer 5: Session
4. Layer 4: Transport
3. Layer 3: Network
2. Layer 2: Data Link
1. Layer 1: Physical

Figure 3: An additional 6 layers provide enhanced capabilities for the original 7-layer Open System Interconnected (OSI) model. The new structure permits consideration of the interaction of groups of computers in support of new operational needs.

Christensson (2000), at the National Defence College, has proposed a 13-layer communication structure model that also includes the ISO 7-layer model. However, Hitchins has pointed out that the first seven OSI layers have a clear “nesting” structure, i.e. of one existing inside the next, which exists inside the next, and so on. Indeed, the notion of envelopes has often been used, with each envelope inside the next, but each with its own address. Hitchins cannot see that this clear and cogent structure has been continued into the new upper layers – at least, not from the titles of the layers.

The additional layers of the 13-layer model incorporate the following: (a). Presentation and manipulation for groups. Hitchins observes here that Presentation (singular, not plural as in the table) is already visible at Layer 6, and is meant to address what is apparently being reintroduced in the new Layer 8. (b). A visual interactive notation or language system, (c). Formal Meetings, (d) Staff and Decision Support Processes, (e). Strategic, Operational and Tactical Functions (SOT) for organisations, (f). Context- and Culture-dependent Issues in organisations (Figures 3 and 4). These new categories of network communication structure recognize the nature and complexity of collaborative command and control environments such as that associated with the Aquarium facility, as described below. Again, Hitchins questioned the need for new layers and asked if is this an attempt to define what should exist as “fine structure” within existing OSI layers 6 and 7.

SWEDISH COMMAND POST OF THE FUTURE FOR NETWORK-BASED DEFENCE

At Swedish National Defence College a future command post test bed has been installed. It is used in three main ways. (1). As a demonstrator for new ways to conduct operations as well as methods and technologies to support those operations. (2) As a support for computer-assisted exercises and (3) As a test bed for research and development projects. Development of the test bed is done in the project Aqua. Use of the layered approach permits more comprehensive development to be undertaken. During 1995-1998 tests were undertaken to identify the optimal size of the co-operating team based on the perspective of group-dynamics. In 1998 the second version of the Aquarium, Mark II, was installed. This is providing the foundation for new research efforts that are outlined in this paper. During the last three years the project Aqua has focused on the layers 8 through 11. The other layers are not in focus for project Aqua. However, layers 8 and below are the focus for activities at the Swedish Defence Material Administration (FMV). The project LedsystT is focusing on building the defence command and control infrastructure (www.fmv.se).

To get a hold of all the different types of data needed for a Command Post of the Future The Swedish National Defence College is actively involved in collecting and sorting the input and output data vectors associated with the installation. This is very much a modeling-driven activity. Those modeling activities are producing simulation programs that support simulations related to the application layer. The modeling activities demand data from which humans are able to recognise patterns. Mathematical formulations are aimed at capturing and representing the dynamics of a complex situation in time-dependent Systems Dynamic Models. Time–dependent models are then extended to include spatially-dependent components, producing spatial dynamics models. Linked to this spatial system and dynamic tools are optimization tools that permit the staff to look ahead and identify optimal force compositions for specific tasks. Based on the layered model we will now further discuss sign systems and Visual Interactive Languages.

Context and Culture-dependent Issues
Strategic, Operational, and Tactical Functions
Staff and Decision Processes
Formal Meetings
Sign Systems (VIL)
Presentations and Manipulations for Groups
Application Layers

Figure 4: Christensson suggests that additional layers are needed to provide enhanced capabilities for the Open System Interconnected (OSI) network communication model.

VISUAL INTERACTIVE LANGUAGES LINK REALITY AND COGNITION

Visual Interactive Language concepts are providing a linkage between the classical military iconography, enterprise-related words, and explicitly-modeled semantic simulations (Figure 5). Such a link is necessary in order to relate the cognitive processes of commanders and their staffs with functioning computer-based representations of the conflict environment. This approach is inspired by the studies in Semiotics, notably by Pierce and his colleagues (see Noth, 1990, for example), theories from linguistics (Grosz and Sidner 1986) and system modeling approaches (Öhlund and Wohed 1993)

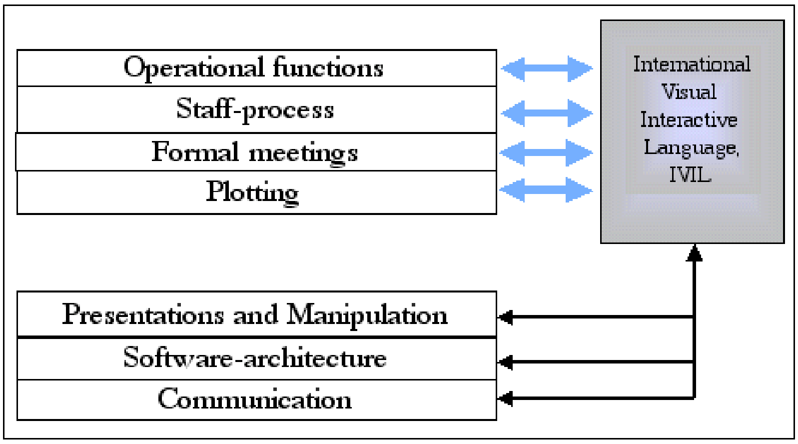

Figure 5: The Visual Interactive Language (VIL) provides links between classical military representations and semantic representations of operational situations.

Existing studied symbols can be divided into Tactical and Administrative Classes (Figure 6). Tactical symbols can be divided into (1) Tactical symbols that can represent the nature of military combat units, its affiliation, battle dimension, status and mission, (2) Tactical Graphics Symbols, such as those representing geo-spatial data and the movement of entities under operational conditions, and (3) Tactical Event Indicators (new and not in the military standard document) that represent or indicate the ongoing events the nature of particular activities such as a combat engagement, rescue activities, or humanitarian assistance.

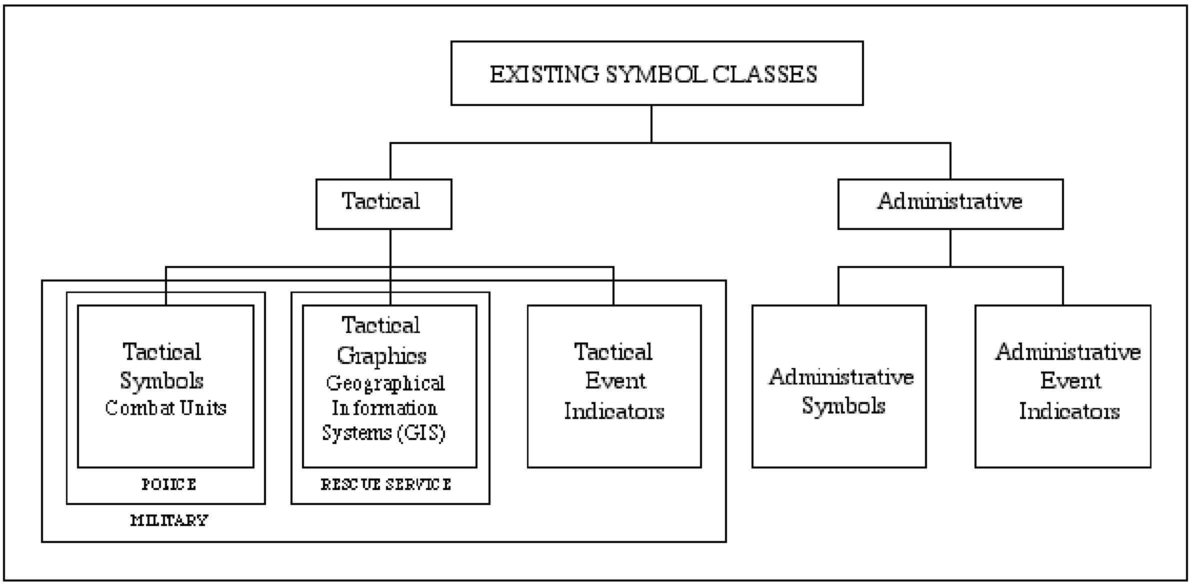

Figure 6: Existing symbols can be divided into tactical and administrative classes.

Tactical Event indicators are a new subject class that can provide a visual representation of the status of entities. It appears that the police may use tactical symbols to support their activities, the police may use some form of tactical graphics symbols. The military may also use tactical symbols and tactical graphics as well as some limited form of tactical event indicators. Administrative symbols can be divided into (1) Administrative Symbols, such as push-buttons, sliders and control widgets, and (2) Administrative Event Indicators such as pop-up windows and menus triggered by events. Administrative symbols are typically used for control and status indication in formal meeting and staff processes.

Some of the tactical symbols mentioned above hare described in great detail in the United States Military Standard 2525B. It is also evident that new operational challenges have created a significant demand for the development of new types of symbols that can represent operational activities in complex societal environments. On-going research by Christensson with visual interactive languages is providing new symbol-based facilities to support crisis management and command and control. The approach is providing visual interactive language-based capabilities that:

- Express the dynamical nature of situations of interest.
- Describe any resources used in a command and control operating system.
- Possess a sufficiently formal structure.
- Work in an interactive group environment.
- Express the properties and behaviors of individual, groups, and organizations.

- Support the Dynamic Decision Process (DDP)-loop.

- Capture the nature of staff-processes and formal meetings.

Studying existing symbol classes for Swedish Authorities as well as United States and NATO Military Standards for plotting and representing a situation, one can identify separate classes. Adding to this class a visual sign class for user administrative purposes, the visual class structure is represented in Figure 6. Tactical visualization involves tactical symbols, tactical graphics, and tactical event indicators.

- *Tactical Symbols* are defined in the United States Mil-Std 2525B as point objects that present information that can be located at a particular position at a specific time. From our systems view we define tactical symbols as visual signs that represent entities that have spatial-, time-, and scale-dependent properties, signifying the mission at state. At least five ways exist to represent entities a combat unit. These include: personnel, organizational structure, technological equipment, trained skill(s) sets, and the mission. The graphical representation of the nature and properties of combat units appears to have begun in Roman times. The Prussian General staff during the 1800s developed a sign-system based on structure of identified organisations. Soviet icono-graphics, by contrast, are more centred on expressing the nature of the action, that is, the imperative or verb of an activity. Figure 7 illustrates the construction of tactical symbol signifying a brigade called *MekB 18*. The field around the symbol contains modifiers or status indicators. This construct serves as a beginning of the development of tactical event indicators as a visual class. In the tactical symbolologies the verbs or the imperatives are represented by icons.

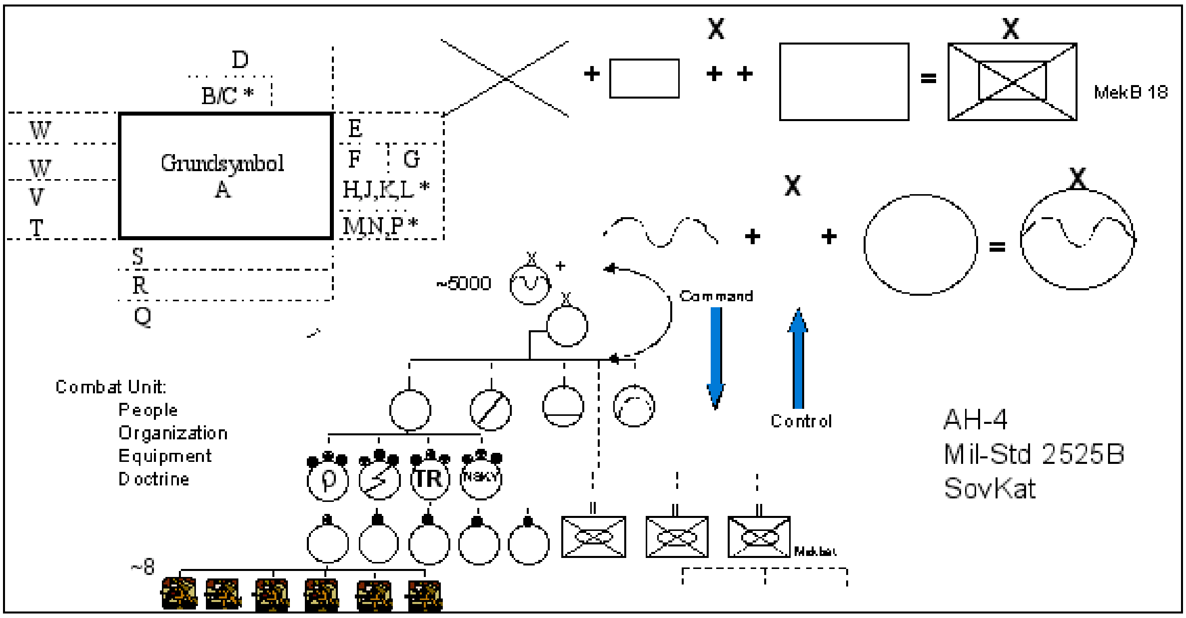

Figure 7: Military tactical symbols provide information military operations support.

- *Tactical Graphics* are defined in The Unites States Mil-std 2525B as “category [that] consists of point, line and area objects that are necessary for battle planning and management. It delineates responsibilities and mission, provide guldens, establish control measures, and identifies items of interest." From our systems view we define tactical graphics as visual signs that signifies entities that are spatial-dependent, scale-dependent, and time-independent. It is with this class of visual sign systems we some times refer to models that are simulated or painted as a substrate or context holder within which the signified combat units are located.

- *Tactical Event Indicators* are not defined in the United States Mil-Std 2525B nor in other manuals as a defined visual class. From a systems dynamics view it is necessary to define the class as a class of visual elements that represent status, outcomes that can be provided in the form of point, line, area, and volume constructs related to geographical information or abstract spaces. Indicators can be linked to morphed changes in this type of indicator.

- *Administrative Symbols* are the widgets with which users can control applications. They depend on the context that other layers are introducing in the command and control system. The electronic based contexts are receiving data from sensors and other staff. The staff and decision supporting software model this data. It's used in higher-level layers.

PRESENTATION AND MANIPULATION FOR GROUPS

Traditionally almost all computer-based applications are developed with the assumption that they are intended for use by an individual. Traditionally one screen and a control device like a keyboard or mouse is to be used by one user. The demand is different if a group is sitting in an around Aquarium or in its planned successor, Visionarium™ with a Visioscope™. That environment involves twenty hands with three variants of controlling devices, eleven private screens, and five shared screens; all integrated to support a social and vivid group interaction. The group of individuals has to be able to handle their view with their devices. Individuals have to be able to interact over the shared screens. Viewed scenes from individuals around the table have to be able to refer to the same object without confusion. Referred data from different viewing angles have to be dealt with. Individuals like to use different types of controlling devices. Presenting the battle space in a multidimensional spatio-temporal way may lead to awareness of all relations and the frictions that occur in conflicts.

In response to these needs and challenges, the Project Aqua at the Swedish National Defence College has developed two types of new presentation devices. They are designed for private use, shared use, and the vertical or horizontal viewing of a image. One technique is stereoscopic and needs polarizing goggles. The other type of technique does not need the use of any goggles. To control viewed data, project Aqua has developed pinch-gloves, gyro-bats, and is investigating fingertip-tracking devices. The demand is from the officers who generally want to use the least technical or complicated devices as possible. System architecture has been developed to link all new control devices and presentations displays and as the manufacturing of more control devices are delivered they are integrated into the overall environment. By doing this, officers in the Joint Headquarter can co-interact as a social group more freely. Individual officers can interact within an overall group to geographical information systems, databases, modeling tools, simulation programs and optimization programs. They can produce orders and navigate etc. with visual representations. With support from the ongoing definition and development work in visual interactive language officers can have be provided with a visual simulation of specific orders.

THE AQUARIUM: A COLLABORATIVE TRAINING AND OPERATIONAL FACILITY WITH MINIMAL PSYCHOLOGICAL DISTANCE

Modeling and simulation can provide dynamic time-, space-, and data-based representations of the environments within which military conflict as well as peace, humanitarian, and other types of operation can occur. Research and development activities being carried out in support of the Aquarium are using a wide range of modeling technologies. These activities are providing realistic facilities for training and for the development of new operational approaches to the command and control of complex combat and societal conflict environments (Figures 8 and 9). The facility is the primary host for the Strategic Management System (STRATMAS) software and was used by an international team to support a post-conflict stabilization exercise study of Afghanistan in January 2003.

In order to be effective, it is evident that a collaborative environment must:

- Assist in building and sustaining shared understanding of the operational context through perception, cognition, and knowledge-building and knowledge-representation activities.

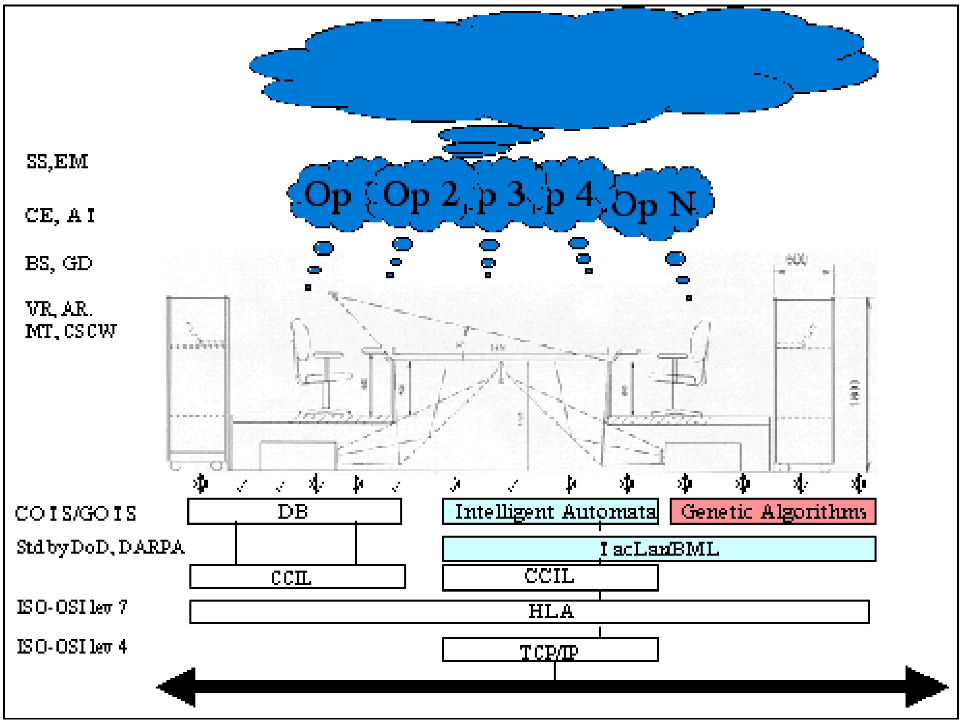

Figure 8: The Aquarium co-operative command and control environment is supported by advanced modeling and simulation and other technologies.

Figure 9: STRATMAS (see below) was used in the Aquarium facility at the Swedish National Defence College in Stockholm to study the post-conflict stabilization of Afghanistan.

- Support and integrate the situation assessment, cognitive, and decision-making styles different individuals.

- Address, identify, and represent the uncertainties inherent in particular situations as well as the potential for different paces of activity at different locations in the overall operational environment.

- Handle and express the result of forecasting activities in ways that can facilitate planning and decision-making and increase overall coordination of the components of an overall force or other organizational entity.

- Provide methods for the integration of civilian and military entities in response to complex societal emergencies such as humanitarian and disaster relief operations, peace operations, and military conflict.

Project Aqua is a long-term research and development project striving to have a specification year of 2010 (Sundin and Friman, 2000). The specification is for a Visionarium™ with a Visioscope™. During its development time the project team has tried, failed, and tried again to build an integrated Swedish Command Post for 2010.

Use by officers during training exercise and other activities helps the project to evolve good design for future devices and procedures. Researchers are helping to identify key questions and to focus core issues. Technology inventors are resolving resolve difficult demands by generating technical solutions. This combination of problem owners such as users, researchers, and inventors is a very good mix.

A good portion of the development lies in the future. This coming year will concentrate on the development of components. By 2005, when the Swedish National Defence College is moving to a brand new location in Stockholm, we will integrate results of these activities to form a Mark III version of the Aquarium. Development and use of notational systems that integrate and fuse data, support officers in the production of models involving situation awareness in terms that can be simulated, assist in focusing the commander's intent in formal goals, and optimize the values of process variables in a shared environment, is a significant challenge that we believe will be met in the near future.

SOCIETAL DYNAMICAL MODELS SUPPORT THE GOVERNANCE AND STABILITY OF POLITICAL SYSTEMS

Societal Dynamics models can consist of Structural, Time-, Time- and Space-dependent, Data, and Adaptable components and may be hosted within the Aquarium (Figure 10).

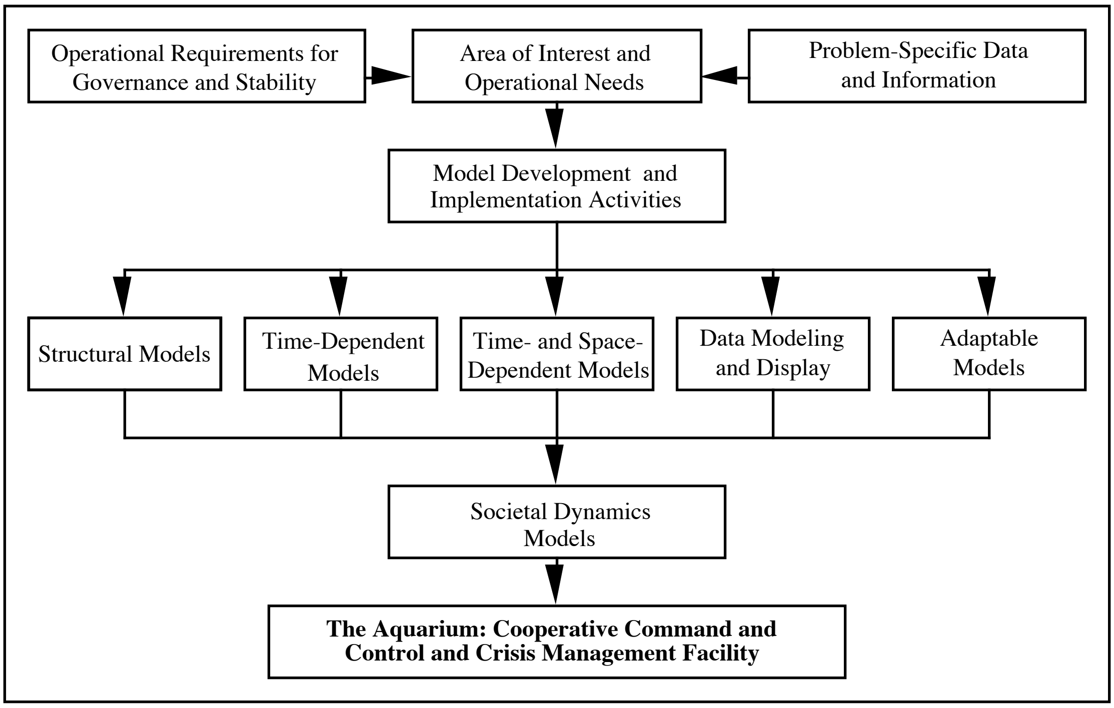

Figure 10: Societal dynamical models can support studies aimed at achieving stability through governance.

STRUCTURAL MODELS

An initial analysis of a system or domain of interest can involve discussions with subject matter experts to obtain descriptions of the nature and problem associated with that area. These activities can be described as Structural Modeling and are aimed at capturing a reflection of experts' internal world models of the domain of interest in words, diagrams, and other constructs. Clearly such constructs will reflect the nature of the patterns and structures generated by observation of and involvement in the activities associated with the domain. Key to detecting the existence of such patterns from natural language descriptions, for example, will be the use of techniques that permit the initial examination of descriptions of domain properties and the interactive construction of sets of models that represent aspects of such processes.

Structural modeling methods support construction of contextual relationships through entity and process identification. Model building can transform isolated data elements into information. Additional activities that place information elements in the context of other information can lead to the formation of knowledge and understanding. Structural modeling can involve a series of interrelated activities including the Hierarchical Issue Method (HIM), The Generic Reference Model, N^2 Charts, Causal Loop Modeling (CLM), and System Interaction Diagrams (SID) (Hitchins, 1992). Details of these activities are provided below.

THE HIERARCHICAL ISSUE METHOD (HIM)

The Hierarchical Issue Method (HIM) is a technique for analyzing complex issues. HIM works from "symptoms" or factors, changes that have been observed, in a situation or system, compared with some supposedly satisfactory previous state. The approach is analogous to diagnosis by a doctor, who seeks as many symptoms as possible, and who uses the possible causes of these many symptoms to derive a cause or causes. As with the doctor, HIM requires an understanding of issue domain. The output from HIM is a set of identified deficiencies, imbalances, and excesses that, if remedied, will restore the *status quo*. This is, in effect, a powerful technique for establishing requirements to resolve complex issues, and it has the unique benefit of being mathematically provable.

THE GENERIC REFERENCE MODEL (GRM)

The Generic Reference Model (GRM) is a description of the internals of any system. At the highest level, it comprises 3 parts: Being, Doing, and Thinking (Hitchins, 1992). Each of these is elaborated (Figure 11). The Being component elaborates to the Form Model, comprised in turn of Structure, Influence and Potential, each of which is further elaborated. Doing elaborates to the Function Model, which comprises Mission Management, Resource Management and Viability Management. Thinking elaborates to the Behavior Management Model, which further elaborates to: Cognition; Selection; Belief System and Excitation.

The GRM can be used in several ways. It is used as a checklist to audit any existing system, simply observing whether that system has within its design a counterpart of the corresponding element in the GRM. For example, the GRM has a feature called homeostasis which, in animals, is concerned with maintaining the internal environment within sensible bounds. Within a socio-technical system there must be features similarly promoting homeostasis, or the system will not be viable. The GRM can also be used for design, by creating a system design that incorporates instantiations of many elements within the GRM.

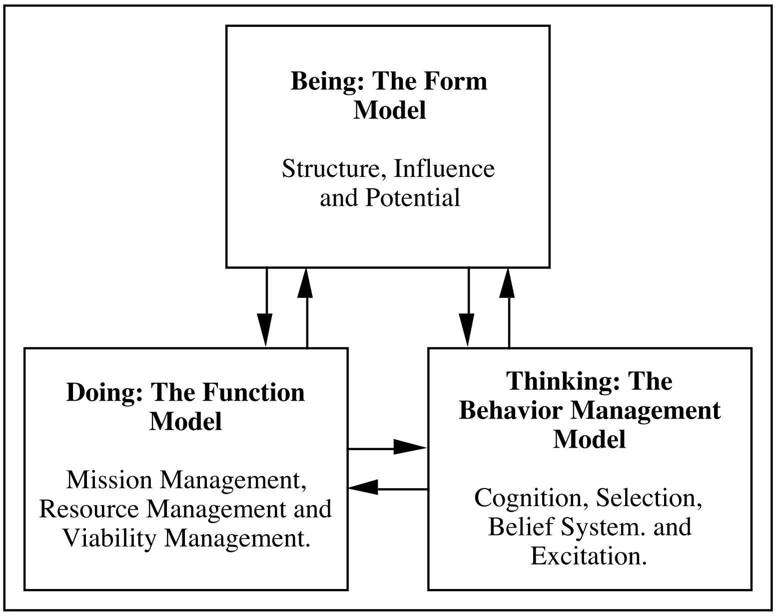

Figure 11: The Generic Reference Model can be used as an auditing device to insure the inclusion of all necessary components in an overall system model.

N^2 CHARTS

N^2 charts are matrices with N rows and N columns, hence the N^2 name. They are used to accumulate information about entities and, particularly, relationships between those entities (Hitchins, 1992). So, a number and variety of players may be entered into an N^2 chart and their various relationships recorded in terms of their nature, frequency, importance, etc. The N^2 chart can be rearranged without altering the logic of the various relationships. In doing this, the relationships form different patterns within the matrix, and these patterns may be significant. A computer program exists, CADRAT©, which can undertake this process automatically, and is so doing, it "untangles" the many relationships, effectively reducing the entropy inherent in the pattern. The end result of this is process is the identification of larger scale groups of relationships, i.e. of higher level systems ("containing systems"), which helps in the management of complexity and in the understanding of complex interactions.

The inputs, processes, and outputs of military force-related advanced technology procurement, supply, and consumption organizations will be identified with the aid of N^2 charts and related methods. This information will be used to describe candidate gene-like entities that could drive evolutionary activities within such organizations. The principles involved in the construction of an N2 chart are shown in Figure 12. Socio-economic entities are shown on the leading diagonal. All outputs from an entity are shown in the row containing that entity. All inputs to any entity are in the column containing that entity. So, any box off the leading diagonal is both an output from one entity and an input to another entity — or, as we would normally say, an interface.

The socio-economic system N^2 chart shown in Figure 13 is interesting because it shows as a complementary set the whole systemic process that could (in principle) be self-sustaining without imports or exports from outside the system. Any imports would enter along the top or bottom edge. Exports would exit at the right or left edge. It is possible to create several of these charts, each representing a different socio-economic system and to interconnect the separate charts. In this case, overall societal activities are made possible through the linking of raw materials, manufacturing, service, and farming industries through their inputs and outputs. Thus, raw materials and industrial products can be used by manufacturing industries to make machines. Machines can be used by service industries for the distribution of food and other tasks. Societies can use those inputs in farming industries, for example, to produce food to support the society.

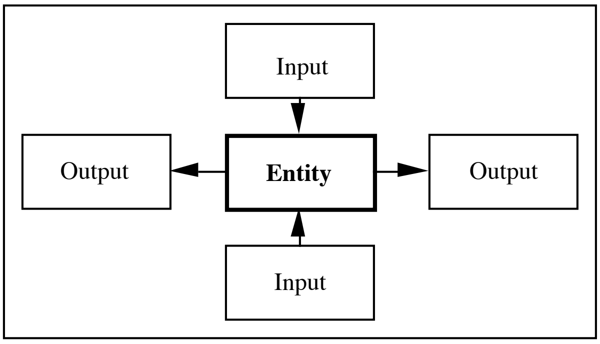

Figure 12: Principles involved in the construction of N^2 Charts could be used to develop an understanding of the process involved in advance technology procurement.

Raw Materials Industries	• Energy • Metals • Woods • Plastics • Composites	• Dated skills	• Domestic Raw Materials	• Fertilizers
• Machinery • Knowledge • Power	**Manufacturing Industries**	• Dated skills • Power • Machines	• Domestic products/materials	• Farm Machinery • Power
• Skilled People • Recyclable raw materials	• Skilled People • Logistics • Recyclable machinery	**Service Industries**	• Power • Food • Distribution • Transport • Communication	• Power • Fertilizers • Pesticides • Husbandry
• Human resources	• Human resources	• Human resources • Dated skills	**Society**	• Human resources
• Recyclable resources	• Recyclable machinery	• Foodstuffs • Dated Skills	• Food	**Farming Industries**

Figure 13: An N^2 Chart illustrates the linked inputs and outputs associated with systemic processes.

CAUSAL LOOP MODELING (CLM)

Causal Loop Modeling (CLM) is a powerful technique, using signed digraphs to develop feedback loop representations, referred to as Causal Loop Diagrams (CLD), of virtually any phenomenon. The world operates through feedback, from Newton's Third Law (action and reaction are equal and opposite) to LeChatelier's Principle. (If a system or set of systems is in equilibrium and a new system is introduced or interaction changed then, insofar as they are able, the systems will rearrange themselves so as to achieve a new equilibrium.). The world, then, is a non-linear place where every action results in non-linear response. CLM enables the representation and, potentially, the dynamic modeling of such phenomena by identifying negative and positive feedback and creating models that are useful in identifying, particularly, non-linear real-world behavior and counter-intuitive responses.

CLM is used extensively by analysts and scientists in the US. In the UK, Influence Diagramming is preferred. Superficially, this looks similar, but Influence Diagramming tends to complicate by incorporating influences that may be difficult to define, and it also tends to overlook feedback. CLM is described in Peter M Senge's *The Fifth Discipline*. CLM is used extensively to represent complex social situations and the influences that activate them. As CLM models become more complex, it becomes less simple to predict their outcome. They are also used, therefore, as an ideal precursor to computer simulation.

An example of a Causal Loop Diagram is shown in Figure 14. In that example, disaffection of individuals from a governing entity is assumed to be caused by the inability of that entity to provide adequate supplies of food, potable water, shelter, employment and other essentials such as protection from crime and violence. Disaffected individuals are considered to be potentially violent, and become actually violent when so motivated. Media reporting and th level of violence creates a perception that violent conditions exist within a society. Such perceptions can trigger demands for the deployment of an international peace force under appropriate conditions. The assembly and deployment of such a force can reduce the level of violence. Sufficient reductions in the level of violence could provide conditions that could lead to the withdrawal and redeployment of the peace force.

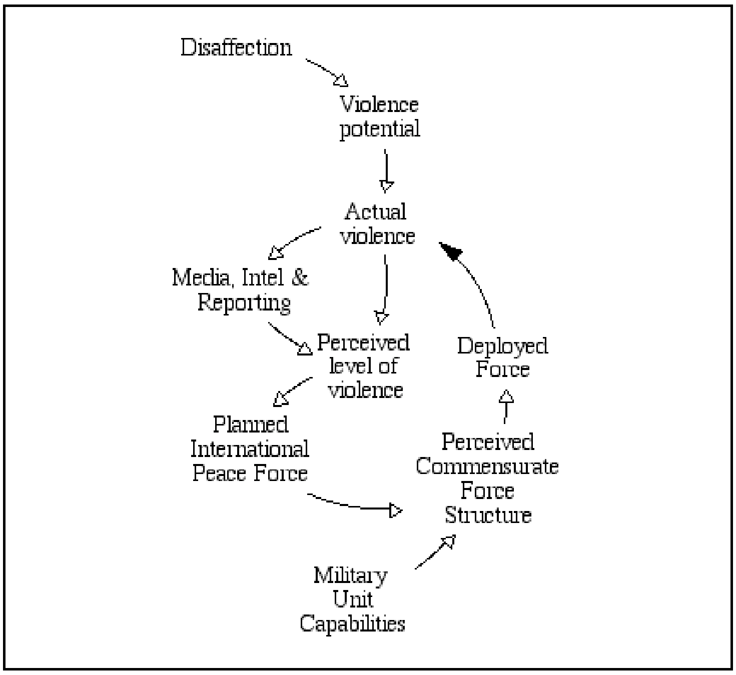

Figure 14: Causal Loop representation of the possible relationships between disaffection, violence, and violence prevention and suppression.

SYSTEM INTERACTION DIAGRAMS (SID)

Use of the N^2 Chart approach to analyze the structure of systems of interest can lead to the identification of related or closely coupled entities an overall system (Hitchins, 1992, for example) These linkages can be illustrated with the aid of System Interaction Diagrams (SIDs) which provide a method for representing the relationships between system sub-components. When used in conjunction with Causal Loop Diagrams, SIDs can be used to identify incomplete structures and missing linkages in an overall system model.

The system represented in Figure 15 consists of four system sub-components or themes, each involving enablers that transform starter conditions into results or outputs. As an example, for a food and environment theme: agricultural machinery, seeds, and fertilizer are the enablers that permit farming, the starter, to generate food products and influence the overall biosphere

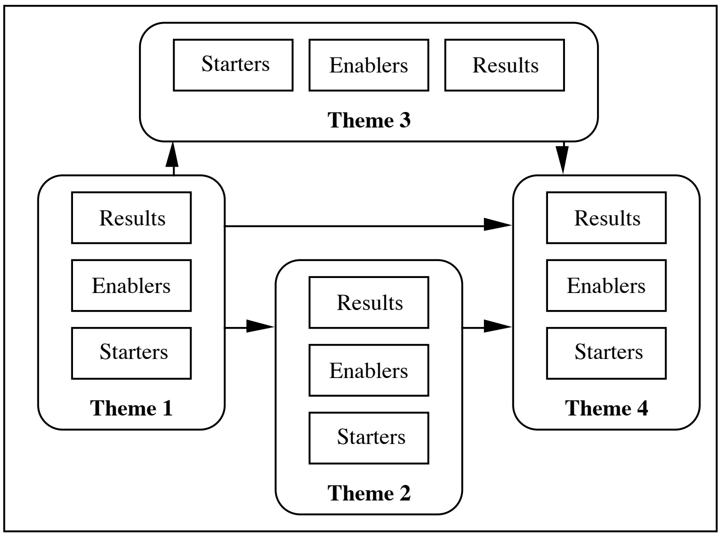

Figure 15: System Interactive Diagrams (SIDs) represent interactions between sub-components (after: Hitchins, 1992).

TIME-DEPENDENT MODELS

Structural models can provide information and knowledge on the structures and relationships associated with systems of interest. A subsequent phase of examining such systems must involve a study of the dynamics of the interaction between identified system components. In order for this to be carried out it is necessary to translate the natural language-based descriptions developed during the structural analysis into appropriate mathematical and computer languages. Structural models developed during the Structural Modeling described above would be used as the basis for time-dependent modeling activities, referred to here as Time-Dependent Modeling. Such modeling can involve the development and use of systems dynamics-based approaches to identify and characterize the dynamic properties such as functional relationships, rates, capacities, transformations associated with entities and properties within an area of interest.

Structural and descriptive information can be used to produce computer models with the aid of STELLA™, Powersim™, Vensim™, and other systems-dynamics software systems. Each of these software systems has its pros and cons. STELLA™ is the preferred vehicle in the present context, since it has been designed specifically to complement Causal Loop Modeling, but the other software systems can be used, as well. As outlined below, use of these models in a series of experimental studies can permit the identification of additional modeling and analysis requirements and provide an enhanced understanding of the nature of entity dynamics within the area of interest. These studies could also permit the identification of gene-like entities, optimization criteria, and other properties that could be responsible for systemic evolution and adaptation in response to changing conditions.

Systems dynamics models have been developed and used to examine the dynamical interaction between military and insurgent forces (Woodcock and Dockery, 1989, Dockery and Woodcock, 1993). Figure 16 shows a non-linear systems dynamics model implemented in STELLA™ that represents the processes associated with peace operations based in part upon the Causal Loop Diagram model in Figure 14. The non-linear systems dynamics-based model is a component of a more extensive model produced to support production of the Strategic Management System (STRATMAS) facility, described below. In the systems dynamics model an internal war in a modeled country is assumed to have caused by disaffection. The internal war creates a modeled perception of violence. Levels of perceived violence over a threshold value can lead to the planning for and deployment of a peace force. The peace force is assumed to be able to act to suppress the level of conflict, The force could be dissolved and re-deployed when suitable reductions in the levels of violence have occurred.

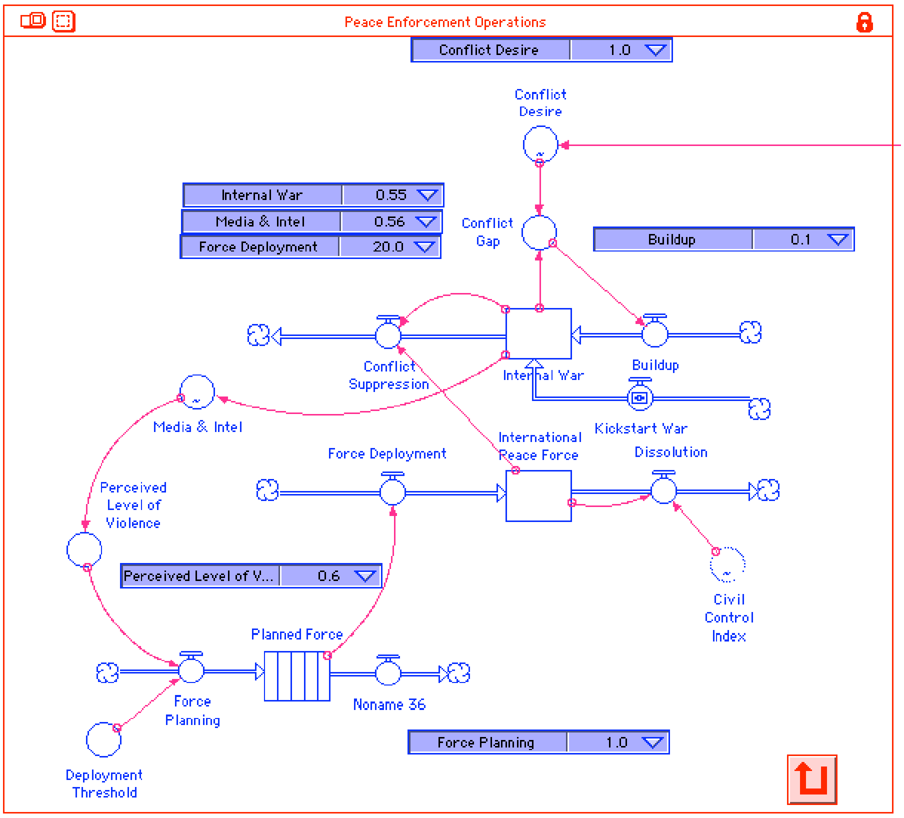

Figure 16: Non-linear systems dynamics-based model describing the deployment of a peace force to prevent and suppress violence in a modeled country of interest.

TIME- AND SPACE-DEPENDENT MODELS

Cellular and Intelligent Automata-based methods have been developed and used to model the spatial dynamics of military combat behavior (Woodcock, Cobb, and Dockery, 1989, for example). Overall behavior in an automata-based model emerges from the interactions between individual automata entities. Specific spatially-dependent behavior can be generated through the use of substrate rules by the automata entities. Substrate rules can represent notional terrain features or other types of geo-spatially distributed properties or societal attributes. Development of prototype automata models can provide facilities for use in undertaking studies of the time- and space-dependent behavior of entities in an area of interest. Such studies could also serve to identify gene-like entities, optimization criteria, and other properties that could serve as component of a model-based evolutionary analysis facility.

Woodcock and Cobb have developed intelligent automata-based combat models that are an extension of their earlier development of models based on cellular automata mathematics (Woodcock, Cobb, and Dockery, 1989a and 1989b, and Dockery and Woodcock, 1993, for example). This work has illuminated the connection between doctrine and training, provided methods for studying the impact of different command structures, and has laid the groundwork for a fresh analysis of modern combat with embedded command and control. With the aid of relatively simple rules and supporting structures, it has been possible to generate patterns of military behavior which qualitatively represent the patterns of maneuver associated with a wide range of historical battles as well as the standard types of maneuver such as frontal attack, envelopment, and flanking described in the United States Army Field Manuals 100-5 and 100-6, for example.

DATA MODELING AND DISPLAY

Time- and Time- and Space- dependent modeling can identify the nature and types of data needed to support the comprehensive study of actual situations of interest. Such data could include, but not be limited to, societal, economic, military, political, medical, demographic, religious and ethnic affiliation, and other data elements defined in terms of appropriate time and space coordinates. Data requirements definition can be followed by data collection and review activities involved at satisfying identified needs and providing an alert where data are unobtainable or undefined.

The collection of needed data could form the basis of specific geo-spatial data bases to be used in conjunction with modeling and simulation for training, education, and operational activities. Selected aspects of these data could be used to construct entities (called Societal Attribute Landscapes by Woodcock, Figure 17). In such constructs, the height of the landscape (represented by a series of contour lines in the Figure) reflects the value of some societal property at that location. These landscapes could form the basis for constructing Substrate Rules for use in conjunction with Automata-based spatial models. Under such circumstances, the behavior of automata entities and other modeling components would reflect the nature of the societal attributes at specific locations.

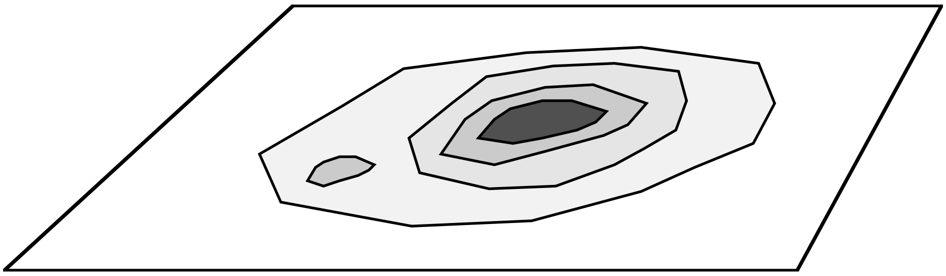

Figure 17: Entities called Societal Attribute Landscapes can represent the geo-spatial distribution of societal properties (after: Woodcock).

ADAPTABLE MODELS

Studies by the authors with a version of the Strategic Management System (STRATMAS) have clearly demonstrated force structure evolution in a modeled combat environment. In that study gene-based procedures were used to evolve such properties as sensor range and weapons range and accuracy for one adversarial (blue) force with respect to those of another (red) force whose capabilities remained fixed. In current research and development activities, similar evolutionary processes are being used to model the planning associated with deployment of military and civilian entities in a series of small scale contingency (SSC) operations. When completed the system should be able to provide information on the optimal structure of military forces and civilian organizations needed for a particular type of operation. In general, genetic algorithms and gene-based optimization procedures could be used to determine the optimal capabilities of interacting entities within an overall societal environment (Figure 18).

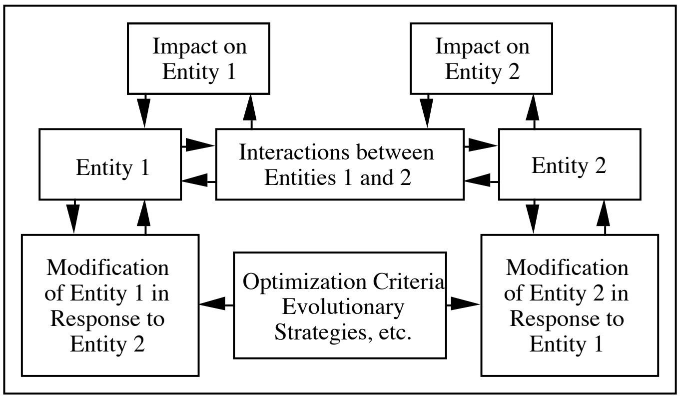

Figure 18: Gene-like properties and appropriate optimization criteria can be used to increase entity effectiveness.

Societal environments undergo changes and capabilities that are appropriate for some situations can become unresponsive or inadequate under other conditions. Processes and procedures aimed at achieving societal stability might be appropriate under some conditions but might become inappropriate and even counter-productive as prevailing conditions change. Work being undertaken by the authors is providing suggestions on how gene-based processes might be used to permit optimal and timely responses to societal challenges in order to maintain overall stability.

SELECTED SOCIETAL DYNAMICS MODEL-BASED SYSTEMS

Societal dynamics model-based systems developed by some of the authors are outlined below

- The Modeling and Analysis of Combat with Embedded Command and Control (MAC3I) System.
- The Counternarcotics Modeling and Analysis Capability (CMAC).
- The Deployable Exercise Support (DEXES) System.
- The Strategic Management System (STRATMAS).

MODELING AND ANALYSIS OF COMBAT WITH EMBEDDED C3I (MAC3I)

Intelligent automata models have been developed by Cobb and Woodcock to model the time- and space-dependent aspects of combat. In those models, selected rules of engagement (which operate by locating the opposition, steering a force toward such opposition, and setting the tactics and attrition rules of the engagement) support the coordinated movement of opposing modeled forces. Rules called reinforcement rules can permit the number of occupied cells to increase as the simulated military forces are reinforced. In other related work, terrain features are simulated with spatially-oriented substrate rules and the automata combat modeling system provides an environment for identifying and experimenting with militarily advantageous terrain features (Dockery and Woodcock, 1993).

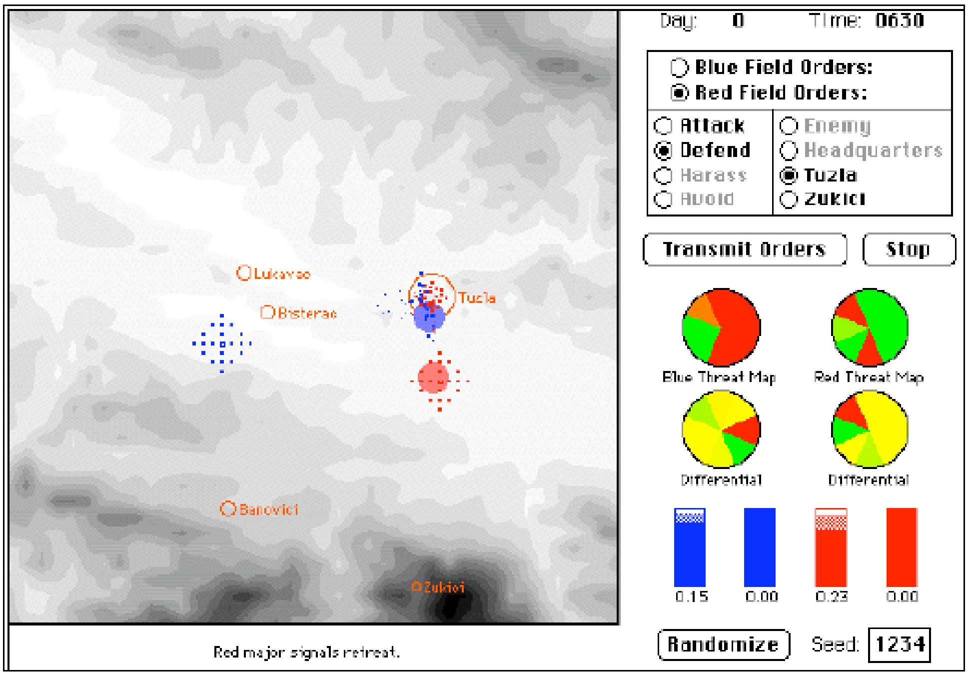

Figure 19: The Modeling and Analysis of C3I (MAC3I) models combat dynamics with the aid of Intelligent Automata-based methods.

In the case of the terrain-based model, it has been possible to create a situation where one of two forces wins a modeled combat engagement with a particular terrain layout and then create situations where the other force is victorious, simply by changing the nature of the terrain through modification of the substrate rules. Automata-based techniques have been used to construct the Modeling and Analysis of C3I (MAC3I) system (Figure 19). This system served as a prototype for the development of additional mare sophisticated models of the combat environment.

THE COUNTERNARCOTICS MODELING AND ANALYSIS CAPABILITY (CMAC)

Automata-based models provide an environment where complicated patterns of military behavior can emerge from the interaction of relatively simple rules of engagement and other properties within relatively small computer environments. Existing cellular automata-based model systems that we have developed permit operator intervention to modify selected parameters of the combat simulation during program execution.

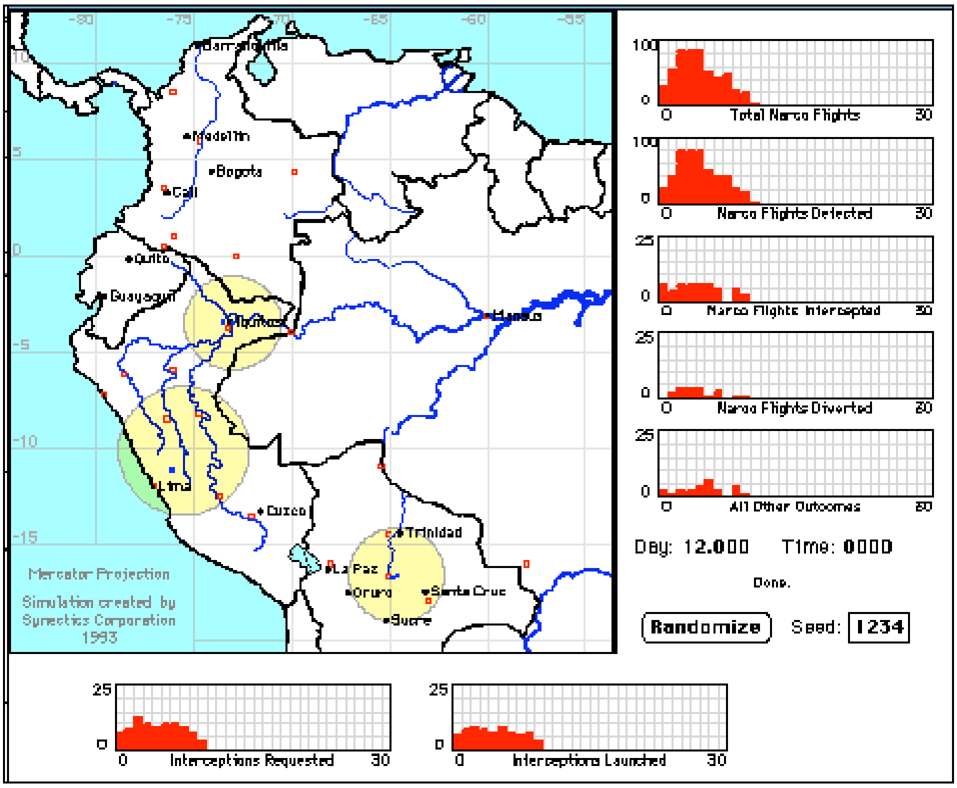

Figure 20: The Counternarcotics Modeling and Analysis Capability (CMAC) has been used to assess the effectiveness of notional counternarcotics air operations.

Automata-based combat simulations can serve as a test-bed for investigations of the impact of command and control, attrition process, terrain, and other factors on combat outcomes. In another application, an automata-based model has been produced to examine the impact of different notional counternarcotics air operations on the success of narcotics trafficking activities in South America (Woodcock and Cobb, 1994). Figure 20 shows the location of narcotics trafficker and counternarcotics assets and movement and interaction of those entities reflect the operation of automata-based operational rules.

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 Sates Southern Command (USSOUTHCOM) (Woodcock, 1996, Woodcock and Cobb, 1998a, b). The DEXES system provides dynamical representations of societal behavior and of the impact of external and internal agents on such behavior (Figure 21). 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.

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. 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 May 2003, DEXES had been used in 14 multinational exercises sponsored by USSOUTHCOM and held in South and Central America.

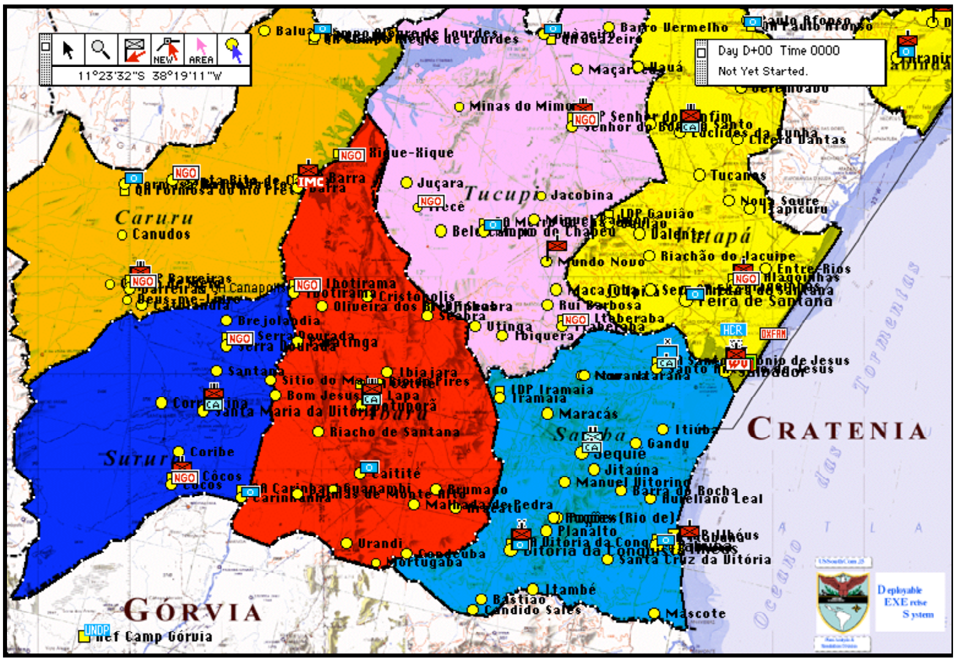

Figure 21: The Deployable Exercise Support (DEXES) system has been used to support 14 peace operations training exercises in south and Central America.

THE STRATEGIC MANAGEMENT SYSTEM (STRATMAS)

The Strategic Management System (STRATMAS) provides a prototype environment for assessing the cost-effectiveness of different combinations of military and civilian entities for undertaking peace enforcement (PEO), peace keeping (PKO), humanitarian assistance/ disaster relief (HA/DR), and non-combatant evacuation (NEO) operations as well as force-on-force conflict (FFC) (Woodcock, Hitchins, and Cobb, 1998). STRATMAS was used to support a post-conflict stabilization study of Afghanistan for the Swedish National Defence College and the United States Joint Staff (J8) at the Defence College in Stockholm, Sweden. STRATMAS provided a model of notional future conditions in Afghanistan and computed the results of the implementation of plans aimed at achieving stabilization and stability after the recent conflict in that country.

COMPUTER EXPERIMENTS CAN PROVIDE INSIGHT INTO GOVERNACE AND STABILITY

The ability to govern and to create stable societal conditions requires a detailed understanding of the dynamics of the political and other processes at work in societies of interest. An initial insight into those dynamics can be achieved through the building and use of models with the aid of STELLA™, a commercial-of-the-shelf systems dynamics-based software system. Models were implemented in that system and then used during the presentation to illustrate their dynamical nature. The presentations included the following.

1. A Societal Dynamics Model that illustrates the formation of and competition between political groups in an overall society.

2. A Simple Disease Model that demonstrates the impact of different rates of infection, recovery, and death on the spread and containment of a disease.

3. The Disaster Relief Strategy Analysis System (DRSAS) that models the impact of a hurricane on the quality of life, violence level, transport infrastructure, and other properties of a notional society.

4. A Post-conflict Stabilization and Peace Operations model designed to provide assessments of the impact of military and civilian actions in Afghanistan.

SOCIETAL DYNAMICS MODEL OF POLITICAL COMPETITION

An initial model describing the growth and interaction between competing political groups implemented in STELLA™ is presented in Figure 22. In this model, individuals are assumed to be recruited into one group (Group1) at a rate determined by the value of the coefficient (Gp1GrowthRatem1) and disaffect from that group at a rate determined by the coefficient (Gp1LossRatem2). Individuals can join the second group (Group2) either directly at a rate determined by the coefficient (Gp2GrowthRtm5), or indirectly after disaffection from Group1 at a rate determined by the coefficient (G2RecrtRatem3). Individuals are assumed to be lost from Group2 at a rate determined by coefficient (Gp2LossRatem4). Overall size of the groups generated by direct entry is determined by the size of the (CarryCap) and (CarryCap2) parameters.

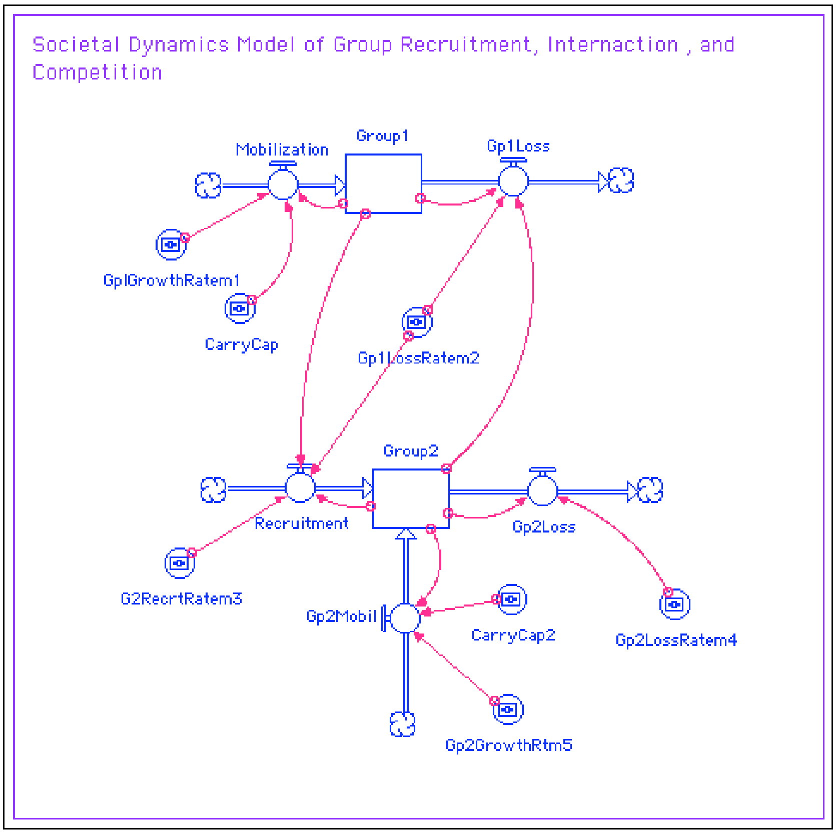

Figure 22: Systems dynamics model representing the dynamics of group interactions that can determine the relative dominance of two competing political parties.

Selection of specific coefficient values in STELLA™ can be accomplished with the aid of entities called sliders. Figure 23 shows the use of sliders to select a particular set of coefficient values for the model. Results of two sets of computer-based studies are shown below. In both cases the values for the model coefficients were set at: (Gp1GrowthRatem1) = 0.1, (Gp1LossRatem2) = 0.001, (Gp2RecruitRatem3) = 0.15, (CarryCap) = 1500, (CarryCap2) = 500, and (Gp2LossRatem4) = 0.0. The first study involved indirect recruitment of disaffected Group1 individuals without direct recruitment into Group2. The second study involved the growth of Group2 both directly from the overall society and indirectly by recruitment of disaffected Group1 individuals.

1. *Study 1: Growth of Group2 by Recruitment of Disaffected Individuals from Group1*. The first study involved growth of Group 2 by the recruitment of disaffected individuals from Group1 without direct growth of Group2 from the wider society (Gp2GrowthRatem5) = 0.0 under such conditions. The overall change in the relative strengths of the two groups is shown in Figure 24, and as a phase portrait in Figure 25. Figure 24 shows that the initially substantially greater strength of group 1 is rapidly reduced. Group2 appears to gain a transient majority during the first 500 time steps, but Group1 achieves, and maintains a small majority over Group2 for the remainder of the run. The

Spiral trajectory of the simultaneous plot of the strengths of Group1 and Group2 generates an entity called a *point attractor* since the limiting value of the trajectory is a single point. The position of that point on the graph is determined by the relative values of the final strengths of the two opposing political groups.

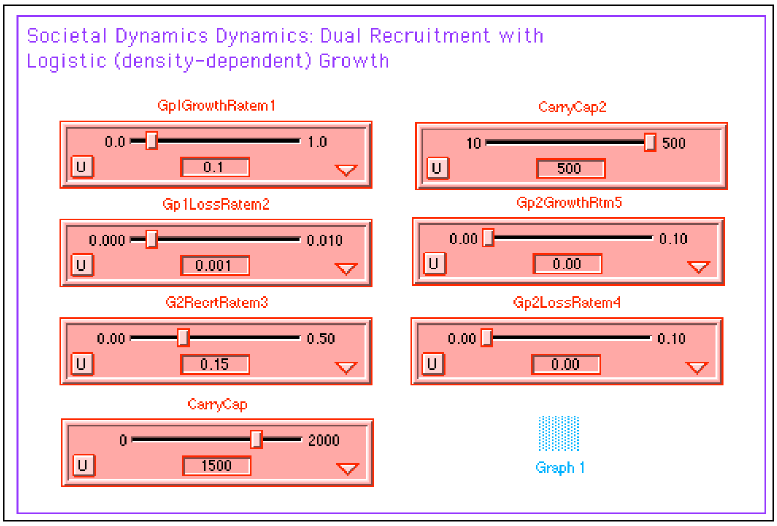

Figure 23: Selecting the values of model coefficients: (Gp1GrowthRatem1) = 0.1, (Gp1LossRatem2) = 0.001, (Gp2RecruitRatem3) = 0.15, (CarryCap) = 1500, (CarryCap2) = 500, (Gp2GrowthRatem5) = 0.0, and (Gp2LossRatem4) = 0.0.

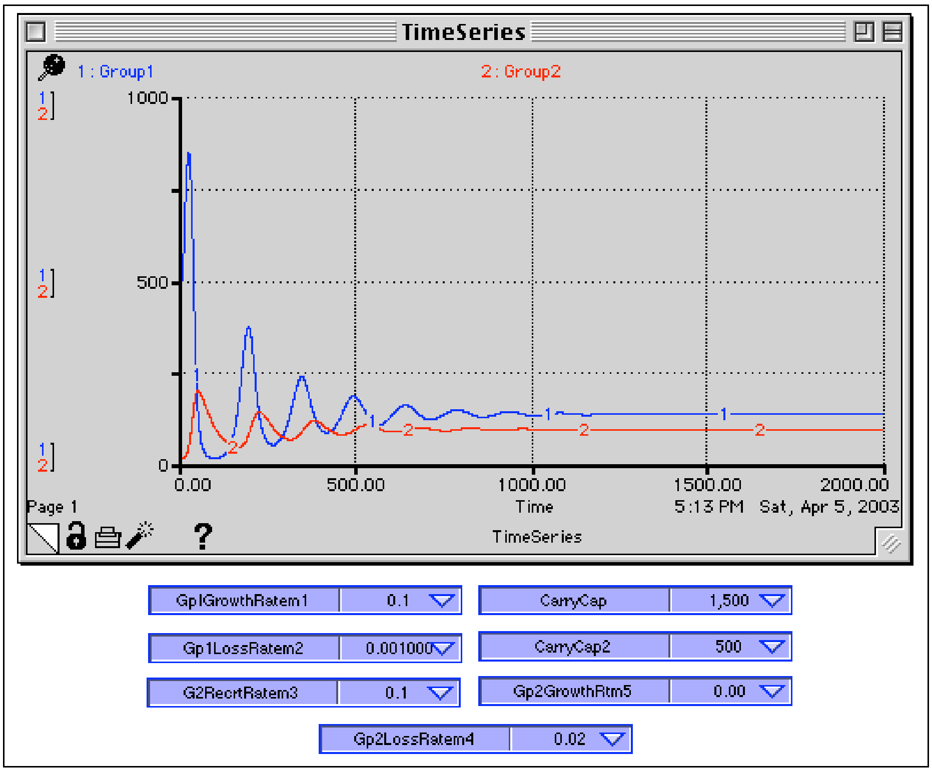

Figure 24: Time series behavior of Group1-Group2 interactions with no independent recruitment into Group2 (Gp2GrowthRatem5) = 0.0.

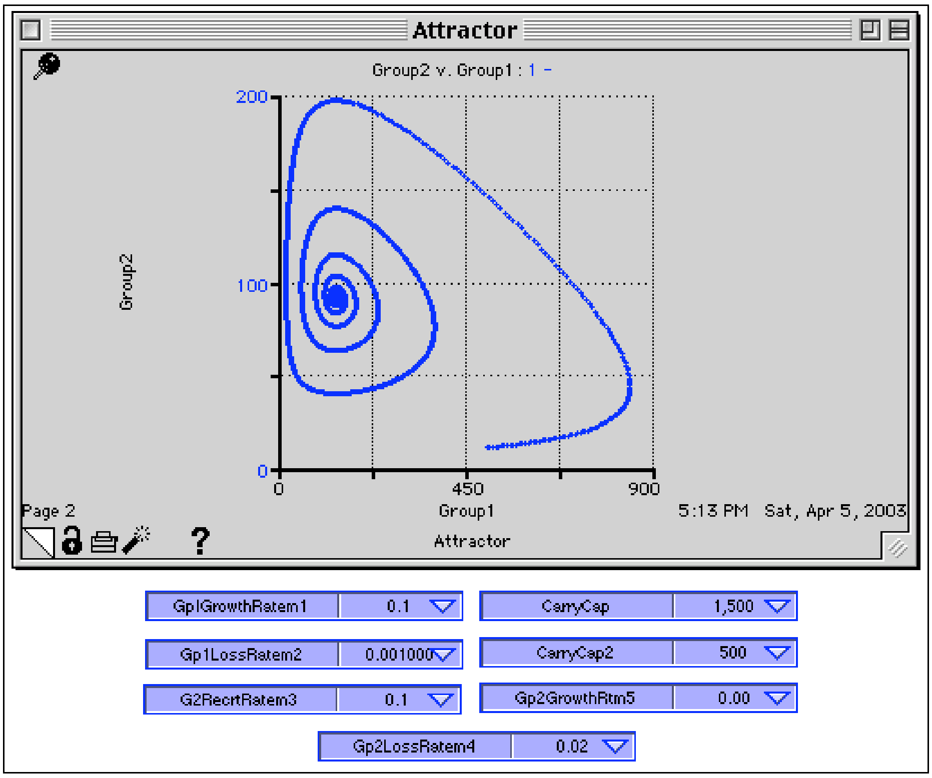

Figure 25: Point Attractor structure representing the behavior of Group1-Group2 interactions with no independent recruitment into Group2 (Gp2GrowthRatem5) = 0.0.

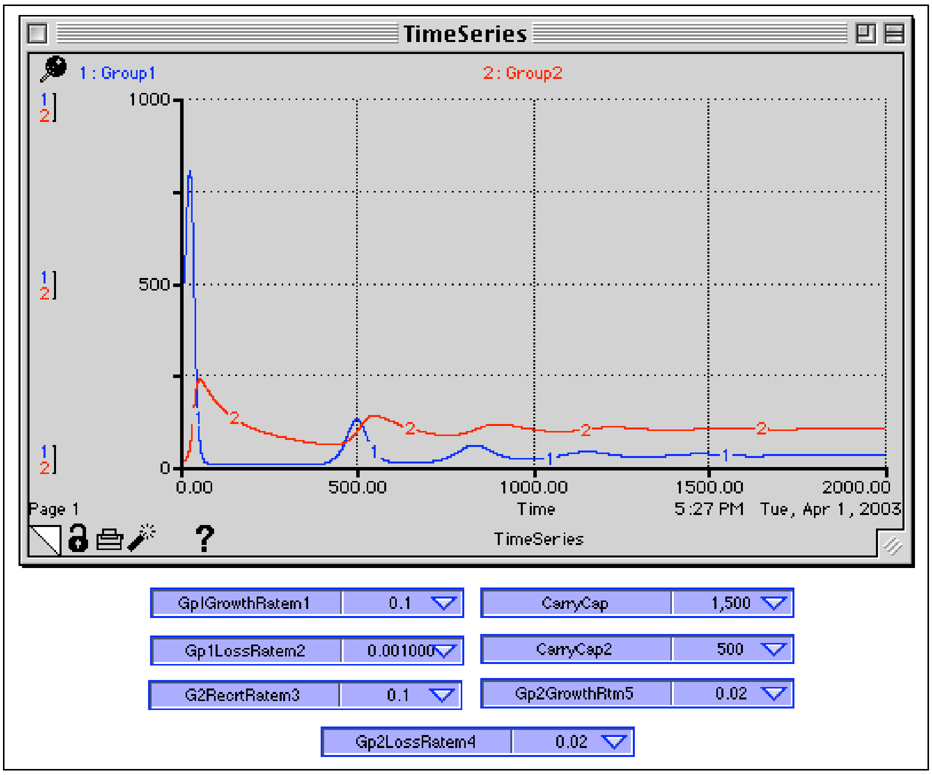

Figure 26: Time series behavior of Group1-Group2 interactions with independent recruitment into Group2 (Gp2GrowthRatem5) = 0.02.

2. *Study 2: Growth of Group2 by Recruitment of Disaffected Individuals from Group1 and from the Overall Society.* Increasing the value of the recruitment coefficient for Group2 to (Gp2GrowthRatem5) = 0.02 (representing a 2 per cent recruitment rate) creates the conditions shown in Figures 26 and 27. In this case, the additional recruitment of individuals into Group2 creates conditions where, after a transient at approximately time step 500, the initially smaller Group2 actually dominates the initially much larger Group1 (Figure 26). The attractor diagram created under these circumstances is also a point attractor (Figure 27).

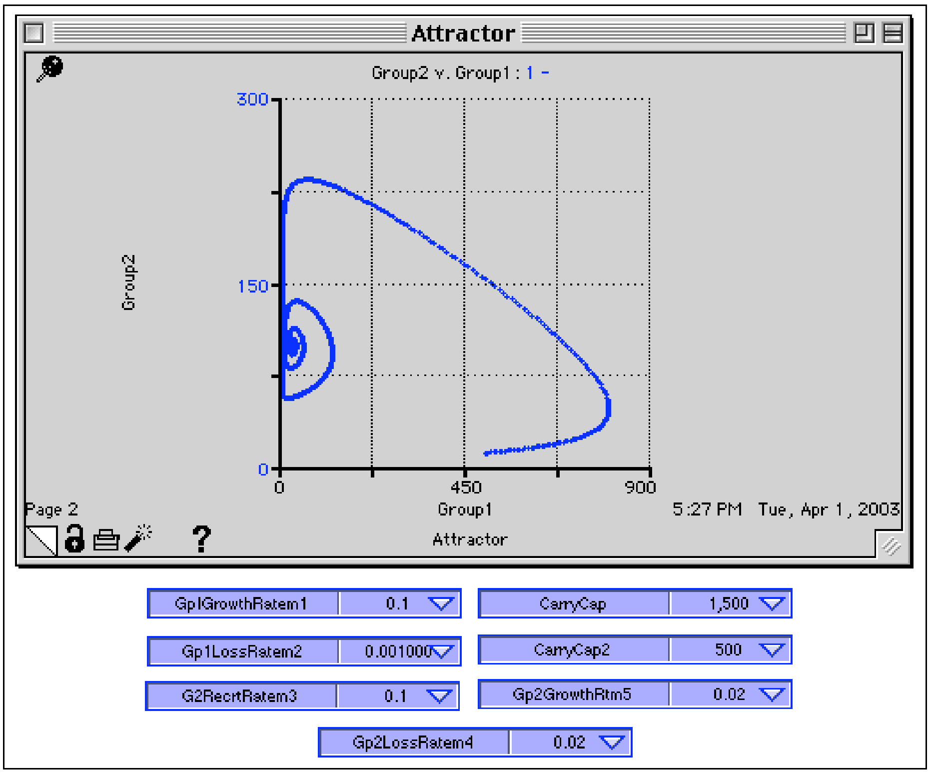

Figure 27: Point Attractor structure representing the behavior of Group1-Group2 interactions with independent recruitment into Group2 (Gp2GrowthRatem5) = 0.02.

This prototype model of the interaction between competing political groups illustrates what can happen when individuals are recruited into, or are lost from, such groups. It is interesting to observe that the relative strengths of those groups can undergo oscillations and may lead to conditions where either group could can achieve transient dominance over the other and that an initial advantage for one side may be overcome and reversed as a result of the nature and magnitude of the interactions between the groups. Development and use of such models could provide initial guidance on what types of political structures might emerge from particular types of interactions as well as the stability of those structures.

A SIMPLE DISEASE MODEL

The ability to govern and to achieve a measure of societal stability can be determined in part by the ability of a ruling entity to understand the impact of disease on overall societal processes. A simple disease model implemented in STELLA™ that illustrated the processes of disease infection, recovery, or death was used as a basis for discussions of those matters (Figure 28). In this model, susceptible individuals (suscept) are assumed to become infected at a rate determined by the value of the infection coefficient (InfectRate). Recovery takes place at a rate determined by the (RecovRt) coefficient and death at a rate determined by the value of the (MortRte) coefficient.

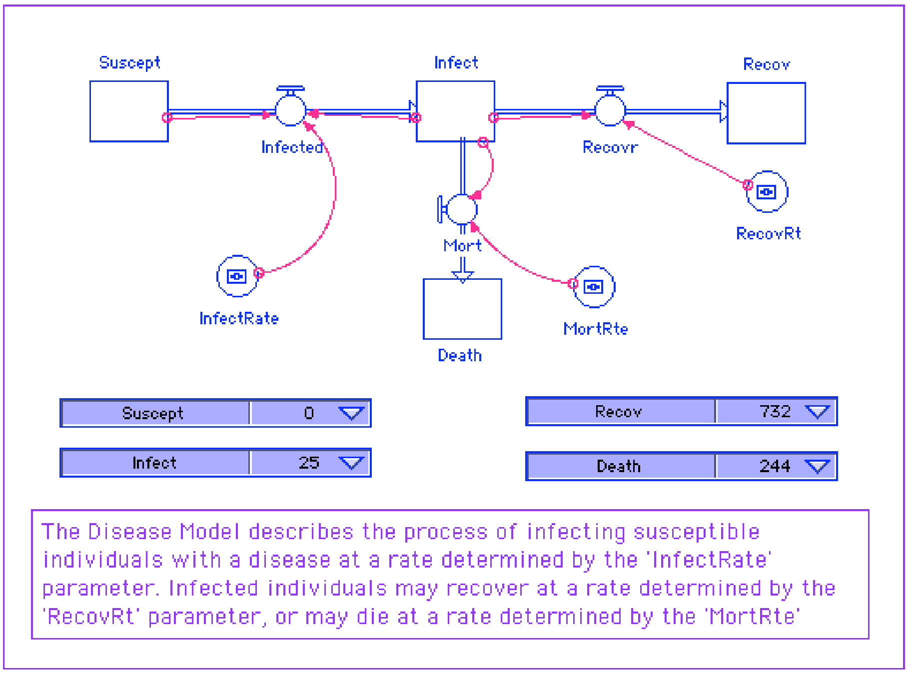

Figure 28: A simple disease model involving infection, recovery and death.

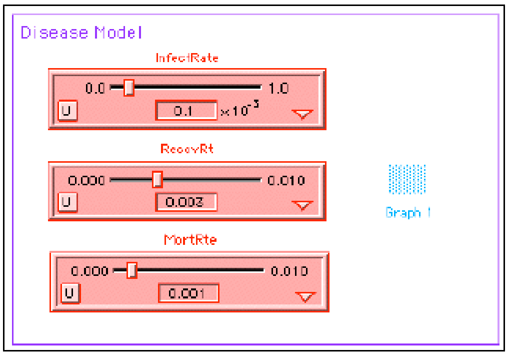

Figure 29: Selecting model coefficient values (InfectRate) = 0.0001, (RecovRt) = 0.003, and (MortRte) = 0.001 for the disease model.

Setting the values of these coefficients at (InfectRate).= 0.0001 (0.01 per cent become infected at each time step), (RecovRt) = 0.003, and (MortRte) = 0.001 (Figure 29) generates the results shown in Figure 30. Of an initial 1000 susceptible individuals and 1 already infected, no susceptible, uninfected, individuals remain after a notional 1000 time steps have elapsed. Some 25 are still infected, 732 have recovered, and 244 have died (Figure 28). The number of infected individuals reaches a maximum at approximately time step 125, and then declines as recovery or death reduce the number of infected individuals (Figure 30). The number of recovered or dead individuals is determined by the relative recovery and death rates used in a particular simulation run of the model (Figure 29).

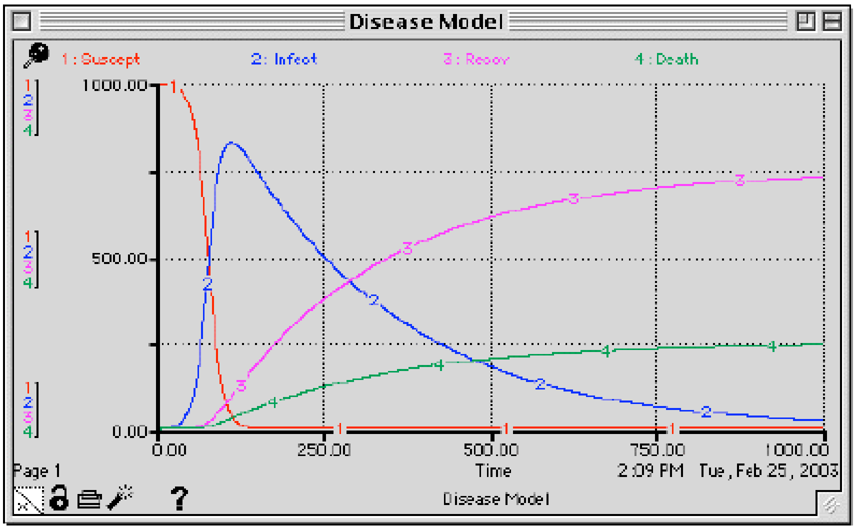

Figure 30: The dynamical behavior of a simple disease model showing the growth of infection and the subsequent recovery or death of infected individuals.

Selection of specific infection, recovery, and death rate values that reflect those properties for actual diseases and societal conditions can provide an estimate of the dynamics of the response of individuals and societies to such diseases. This relatively simple model can be enhanced to include the impact of public health and medical care processes on disease prevention and recovery (Woodcock, 2004). Additional enhancement and validation and verification activities can foster the development of disease models that could be used to assist policy- and decision-making aimed at protecting individuals and stabilizing medical conditions within an overall society.

THE DISASTER RELIEF STRATEGY ANALYSIS SYSTEM (DRSAS)

A measure of the stability of a political system is its ability to respond to and recover from natural disasters created by hurricanes and other methods. Production of the Disaster Relief Strategy Analysis System (DRSAS) was undertaken by Hitchins and Woodcock in support of development of the Strategic Management System (STRATMAS) (Figure 31). DRSAS is implemented in STELLA™ and its production and use provided key understanding and knowledge needed to produce STRATMAS. While it is outside the intended scope of this paper to provide a detailed review of DRSAS capabilities, a limited review of the use of the system to model the impact of a hurricane on societal stability will be provided.

The DRSAS facility provides models of processes involving the provision through a complex transport infrastructure of food, water, fuels, medicines, and emergency shelters to sustain a population after a hurricane. The hurricane is assumed to have many impacts, including the following:

- Transport is interrupted so the supply of relief materials and other essential becomes spasmodic at best.

- Roads and railways are washed away, and transport systems become overloaded and start to break down.

- Drinking water becomes contaminated, introducing the spectre of disease.

- Interruption of the supply of fuels may cause a loss of electrical supply that would threaten domestic heating and cooking, and other essential activities.

- Emergency relief services are themselves affected negatively.

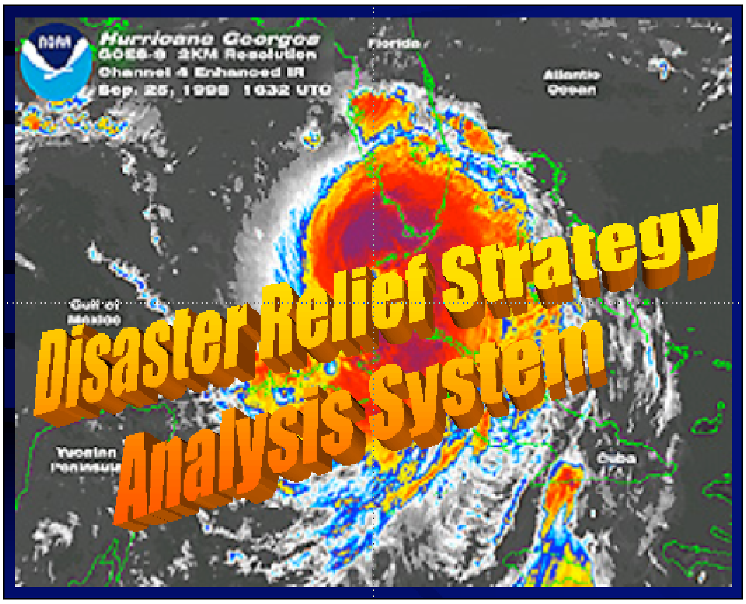

Figure 31: The Disaster Relief Strategy Analysis System (DRSAS) provides an environment for assessing the impact of different disaster relief policies and resource allocation activities.

The DRSAS simulation also allows the injection of humanitarian relief in may forms. The timing and amount of relief are under the control of the user of the system so that the user could examine the impact of different relief strategies. Overall conditions in the modeled society are expressed in terms of a composite Quality of Life (QoL) Index (Figures 32 and 33). The models are used to compute the level of societal violence reflecting the nature and behavior of a notional society before, during, and after a hurricane. An insurgent model contained in the overall DRSAS framework represents the impact on the behavior of insurgents of the highly stressed environment following devastation caused by a hurricane.

- <u>A Force 1 Hurricane:</u> The effect on the Quality of Life Index and Violence Index (reflecting the level of violence within the modeled society) of a Force 1 hurricane at notional time 340 is shown in Figure 32. Variations in the Quality of Life Index occur in the model before the onset of the hurricane and it appears that the hurricane reduces the level of the Index. A relatively minor increase in the level of violence (perhaps caused by a breakdown in social control and opportunistic looting) starts at approximately time 350. Transport and vehicle maintenance models included in the overall DRSAS facility provides an estimate of the number of vehicles available for moving relief supplies and other cargoes. In this case some 22 vehicles are available for transport activities at the end of the simulation.

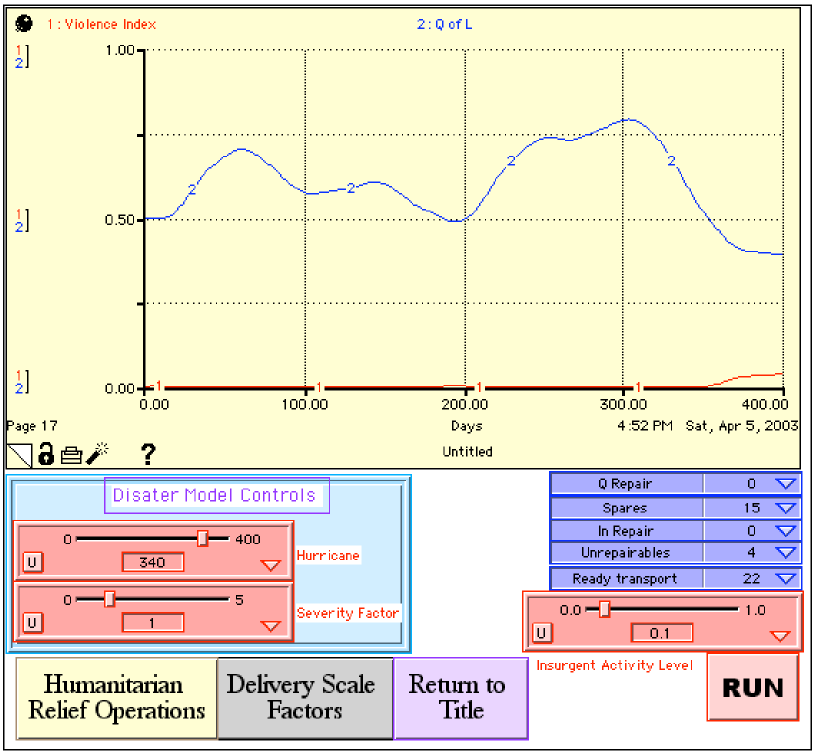

Figure 32: The impact of a Force 3 hurricane at time 60 on the Quality of Life and Violence Indicies for a modeled society.

- <u>A Force 3 Hurricane:</u> A Force 3 hurricane occurring at time 60 appears to have a much greater impact on the Quality of Life and Violence Indicies (Figure 33). The quality of life undergoes a significant reduction compared with the effect of the weaker hurricane shown in Figure 32. By contrast, the level of violence shows significant increases after approximately time 100. The stronger hurricane appears to have reduced the number of available vehicles to six, compared with 22 in the case of the weaker hurricane.

Appropriate levels of validation and verification and subsequent modification and enhancement driven by those processes could provide a future DRSAS facility that might be capable for assessing the impact of different disaster relief plans aimed at supporting recovery and reconstruction. Adequate and timely presentation of such relief could serve to stabilize a society whose people and facilities have been battered by a hurricane.

POST-CONFLICT STABILIZATION AND PEACE OPERATIONS

A series of models using Causal Loop and Systems Dynamics principles were developed during the Strategic Management System (STRATMAS) project in order to gain insight into the overall nature of a society in crisis such as Afghanistan (Figure 34). Hitchins and

Woodcock were involved in the development of the initial Causal Loop models and Hitchins then used the STELLA™ software system to develop systems dynamics representations of those initial models. These model-building activities were intended to identify the nature of the factors and processes at work in such societies and the dynamics of the interactions between those factors and processes. Results of some of these activities are reported below.

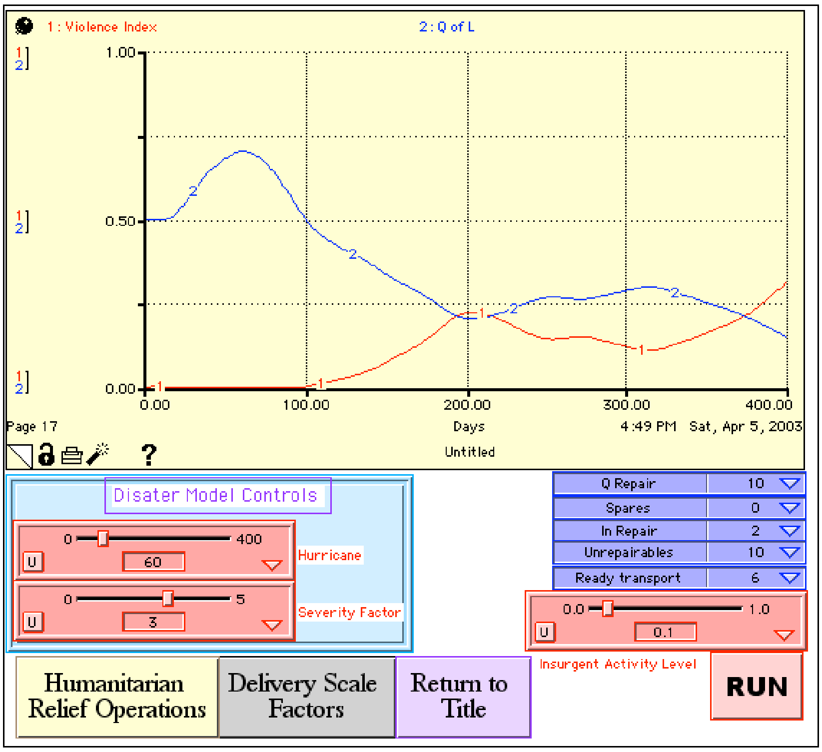

Figure 33: The impact of a Force 3 hurricane at time 60 on the Quality of Life and Violence Indicies for a modeled society.

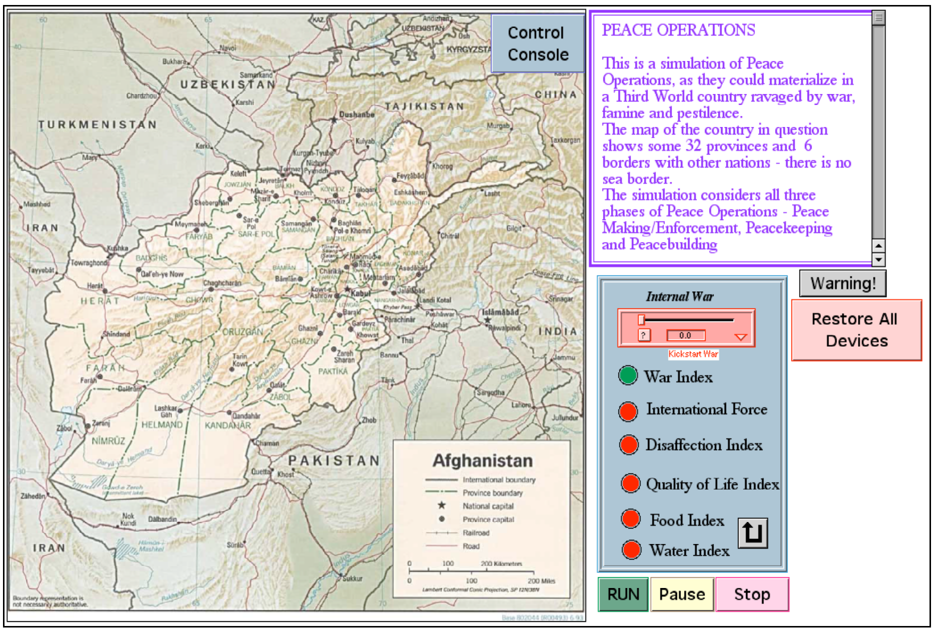

Figure 34: Map and indicator display provided by the STELLA™ model.

The ensemble of models implemented in STELLA™ was used in a series of studies to investigate the impact of specific sets of model parameter values on overall societal activities and performance. In particular, the levels of food, water, shelter, and financial aid were set at either a high (or 'maximal') or zero level.

1. *In the first experimental study*, the food index, the level of imported water, the level of international shelter aid, and the level of financial aid were all set at zero. The level of internal war rapidly increases to reach a peak at about month 20 and then declines but remains significantly above the initial levels by month 80 (Figure 35). The level of international police increases in a quasi-linear manner from zero to approximately 1500 at month 90, and remains at that level for the remainder of the simulation period. The food and water indices remain at zero.

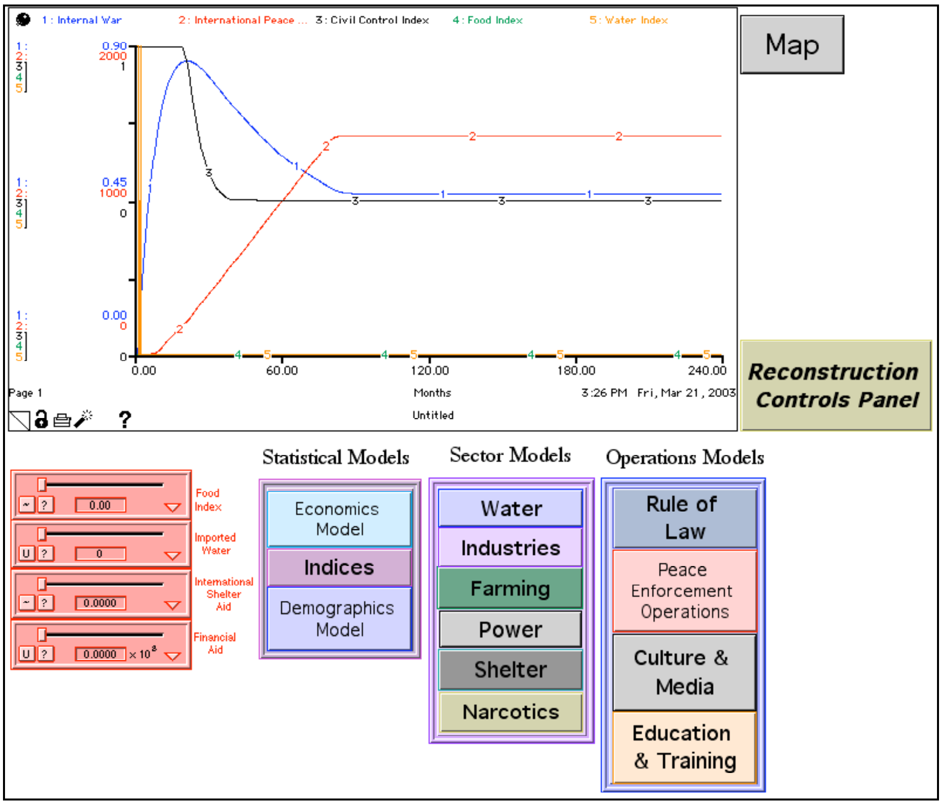

Figure 35: Impact of zero food, water, shelter, and financial aid on selected societal conditions.

2. *In the second experimental study*, use of the systems dynamics model involved analysis of the impact of maximal levels of food, water, shelter, and financial aid. The food index was set at 1.0, the level of imported water was set at 10, the level of international shelter aid was set at 1.0, and the level of financial aid was set at \$100M. With these settings the level of internal war began at an intermediate level and gradually declined for some 120 months of notional elapsed time, and then declined to approximately zero after 180 months (Figure 36). The level of international police reached a maximum approximately at month 80, and remained at that level for some 15 to 20 months, and then declined to a relatively low level after 180 months. The civil control index declined from a high to a relatively low value after some 30 months, remained at that low level until month

60, then increased to the initial high level. Both food and water indices remained at their high initial values.

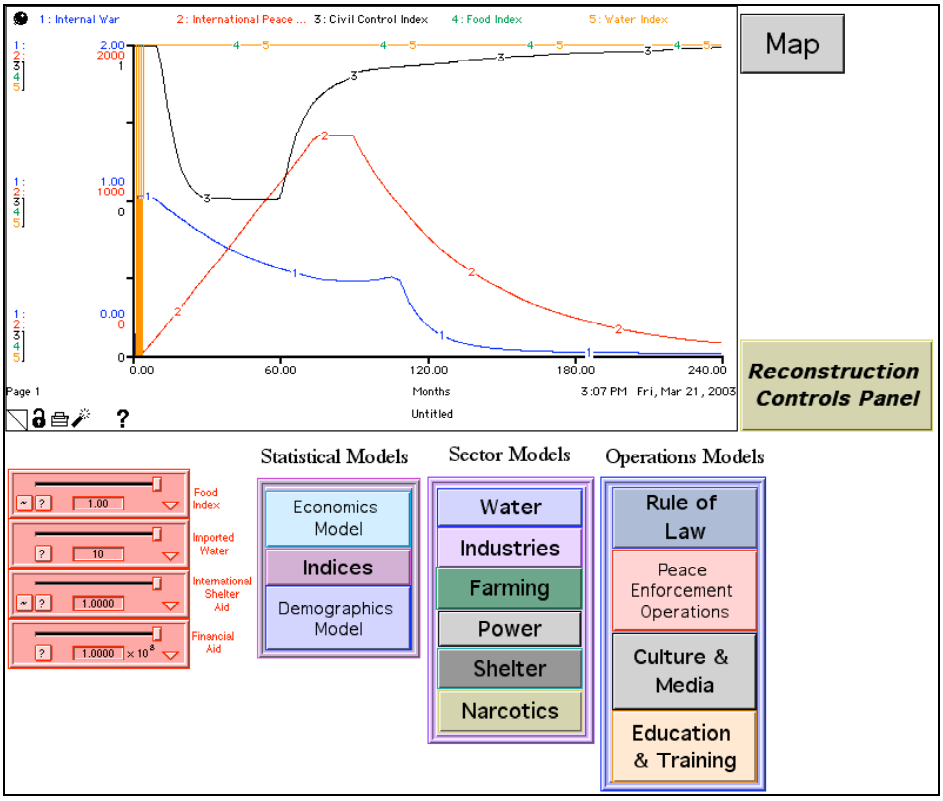

Figure 36: Impact of maximal food, water, shelter, and financial aid on selected societal conditions.

Additional model coefficient values are available for modification within this system and further results can be obtained from based on the selection of different sets of those values. Extensive use of the system in that way has provided insight and guidance that has been used to support development of the Strategic Management System (STRATMAS) mentioned above. In this way, the time-dependent perspective obtained from development and use of the systems dynamics models has been extended to include both time- and space-dependent representations in STRATMAS. The STRATMAS software was hosted in the Aquarium and used with success to support a post-conflict stabilization study of Afghanistan at the Swedish National Defence College for the College and the United States Joint Staff (J8) in January 2003. Further use of STRATMAS for other related studies is contemplated in the near future.

DISCUSSION

Recent terrorist events in the United States, and their echo in Afghanistan, Iraq, and elsewhere have demonstrated the need for an informed understanding of the causes of local events and their global consequences in order to support governance and the achievement of stability. Development of such an understanding demands the production and use of new types of facilities for the dynamic integration and assessment of both military and civilian information that elucidate ongoing behavior and identify beneficial courses of action. The authors believe that a combination of the research results obtained from the development of collaborative command and control and crisis management capabilities and appropriately validated societal dynamics-based models will provide significant inputs to the production of such facilities.

The paper reviews new command and control and crisis management procedures involving effective collaborative environments and Visual Interactive Languages (VIL) under development produced at the National Defence College in Sweden. Modeling is providing dynamic time-, space-, and data-based representations of the environments within which military conflict as well as peace, humanitarian, and other types of operation can occur. Selected models have been implemented in small, agile, computer systems. Those models include the following: (1). The Modeling and Analysis of Combat with Embedded Command and Control (MAC3I) System, (2). The Counternarcotics Modeling and Analysis Capability (CMAC), (3). The Deployable Exercise Support (DEXES) System, and (4). The Strategic Management System (STRATMAS).

Other models implemented STELLA™ were used to illustrate their dynamical nature. These included the following: (1). A Societal Dynamics Model of political competition, (2). A model of the impact of different rates of infection, recovery, and death on the spread and containment of a disease, (3). The Disaster Relief Strategy Analysis System (DRSAS) that models the impact of a hurricane on the quality of life, violence level, transport infrastructure, and other properties of a notional society, and (4). A Post-conflict Stabilization and Peace Operations model designed to provide assessments of the impact of military and civilian actions in Afghanistan.

It is hoped that on-going work by the authors and their colleagues will contribute to the development of the new tools and methods needed to meet the new and emerging threats and challenges to governance and stability. These tools and methods could be used to produce new types of co-operative policy-making and decision-support facilities that are responsive to the new challenges. These challenges include the widening spectrum of conflict, new terrorist biological and chemical threats, and the need for military forces and civilian entities to participate in peace, humanitarian, and other types of operation.

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