The Dynamics of Societal Processes

Professor Alexander E.R. Woodcock, Ph.D.

Societal Dynamics Research Center
School of Public Policy
George Mason University,
Fairfax and Arlington, Virginia, U.S.A.
e-mail: aerw@gmu.edu

Alexander E.R. (Ted) Woodcock is a Research Professor in the School of Public Policy at George Mason University. Previously he was Chief Scientist and Vice President at BAE SYSTEMS (formerly Synectics Corporation), Fairfax, Virginia. He is a Foreign Member of the Royal Swedish Academy of Military Sciences. Woodcock is also a Guest Professor at the National Defence College, Stockholm, Sweden, and was a Visiting Professor at the Royal Military College of Science, Shrivenham, England for 10 years. He is actively involved in the development and implementation of societal dynamics models of military, political, economic, and other processes for the modeling and analysis of low intensity conflict, peace and humanitarian operations, and related areas. Woodcock is Project Director for the Strategic Management System (STRATMAS) project that is producing a facility that uses genetic algorithms and intelligent automata methods for the definition and optimal deployment of civilian and military entities in peace and humanitarian operations. Woodcock is Co-Chair, Proceedings Editor, and a Founding Member of the Cornwallis Group. He has a Ph.D. in Biology and an M.Sc. in Biophysics from the University of East Anglia in England, as well as a B.Sc. (with honours) in Physics from Exeter University in England. He is a Full Member of Sigma Xi.

INTRODUCTION

The achievement of stability through governance requires a fundamental understanding of the dynamical nature of societal processes. Models of four types of important societal processes have been produced to facilitate the development of such an understanding. These models have been implemented in systems dynamics-based software and were used in a series of tutorial demonstrations during the Cornwallis workshop. Details of the model-building process and selected properties of the tutorial models are presented below.

The models provide an environment for undertaking computer-based studies of the dynamics of societal processes and have formed the basis of the following four case studies. The case study models presented below were developed by the author and used in a graduate-level course on Modeling and Simulation for Peace Operations in collaboration with Professor Davis at George Mason University in 2003.

1. Military and Security Concerns involving the use of security forces to reduce violence caused by disaffected individuals.

2. Disarmament, Demobilization, and Reintegration (DD&R) as a prelude to threat reduction, post-conflict stabilization, and reconstruction.

3. Public Health and Medical Care effectiveness in reducing the impact of diseases caused by infection and the lack of potable water and adequate food supplies.

4. Refugees and Displaced Persons and their movement and re-settlement.

The models were presented in a seminar that preceded workshop discussions of a range of topics associated with the processes of governance and stability. The paper continues with a review of the model-building processes used by the author, and then reviews some of the materials presented to the workshop participants.

MODEL BUILDING AND KNOWLEDGE DEVELOPMENT

Models provide representations of reality that can be used in studies and experiments aimed at increasing the understanding of overall system behavior. Model-building can involve several stages of description and translation from natural to mathematical to computer language(s) and back again in a cycle of knowledge development (Figure 1). Observations of the behavior of a system of interest can lead to an initial description of that system with the aid of a natural language. Translation of that description into a mathematical language can lead to an initial description of the input, process, output, and other properties and can produce an initial mathematical model of the system. Further translation into a computer language can produce a computer-based model. The addition of appropriate user-interface and data and graphics display facilities can produce an environment for undertaking computer-based experiments and studies.

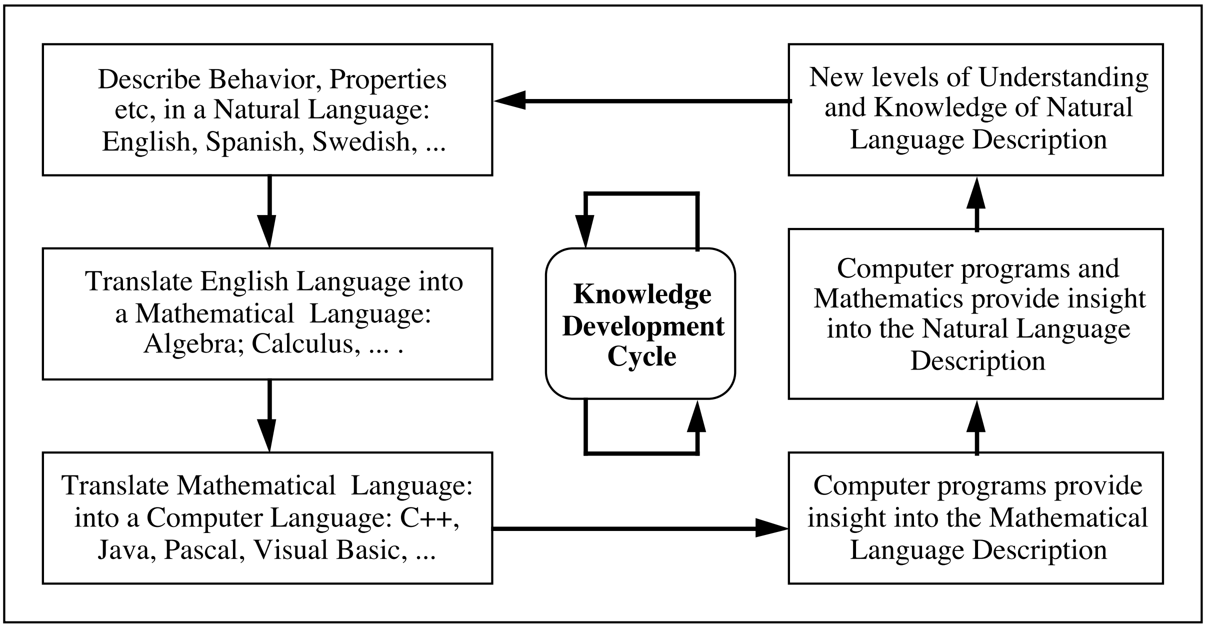

Figure 1: The Knowledge Development Cycle involves translations from natural to mathematical to computer languages in order to generate new levels of understanding.

Computer experiments can provide insights into the nature and behavior of the embedded mathematical model. Analysis and discussion of these results can provide a deeper understanding of the nature of the system of interest. An enhanced natural language description based on those discussions can lead to the production of enhanced mathematical and computer-based models. Continuation of these processes can generate new knowledge and deeper insight into the nature and dynamics of the selected system of interest.

The process of knowledge development can be illustrated by observation of the physical behavior of a simple pendulum and development of models that describe such behavior (Figure 2). Once displaced from the vertical, the pendulum will oscillate backward and forward through the vertical. It is well known that the movement of the pendulum can be described by a mathematical equation of the form of a sine wave: y = amp.sin(x), where y is the position of the end of the pendulum, (x) is a function of the angular displacement, and (amp) is the amplitude of the movement, dependent upon the length of the pendulum.

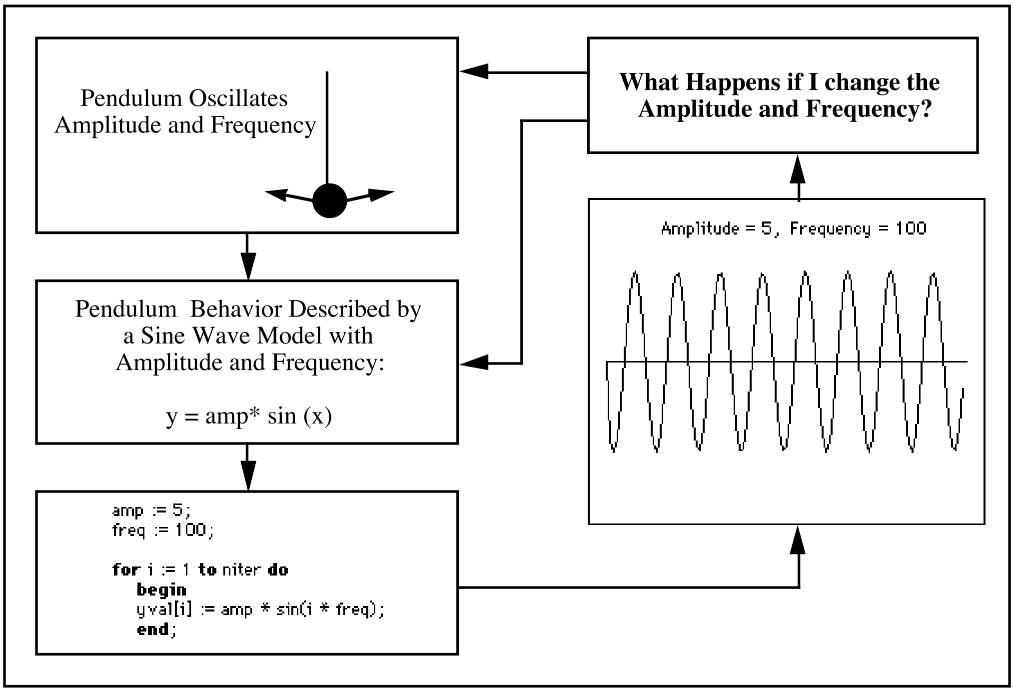

Figure 3: Development of a mathematical model and its implementation in a computer language provides a facility for studying the impact of changes in the amplitude and frequency parameters of that model.

The mathematical model can be translated into a computer language, and such a translation into the Pascal computer language is shown in Figure 3. In this case, the angular measure has been represented as the frequency of oscillation multiplied by a time parameter to describe the pattern of movement as time progresses. Solution of the computer model is achieved by iterating the equation over many time steps. An appropriate graphics display routine has been used to display the results of iterating the computer model many times. Figure 3 shows the oscillation of the pendulum as it is initially displaced from the vertical to one side, moves backward through the physical vertical (illustrated by the middle value of the wave form), moves to the other side of the vertical, returns to the vertical, and so on when the amplitude and frequency values are set at 5 and 100, respectively. The graph shown in Figure 3 is a model-based prediction of the pattern of movement generated by a physical pendulum with an amplitude of 5 and a frequency of 100 displayed as a function of time. Here time is represented by the horizontal axis with an arbitrary scale. The computer program can be modified to generate patterns of behavior of other modeled pendula by changing the values of the amplitude and frequency terms in the model. Figure 4 shows additional predictions of the behavior of pendula with amplitudes of 4 and 2 and frequencies of 25 and 50, respectively.

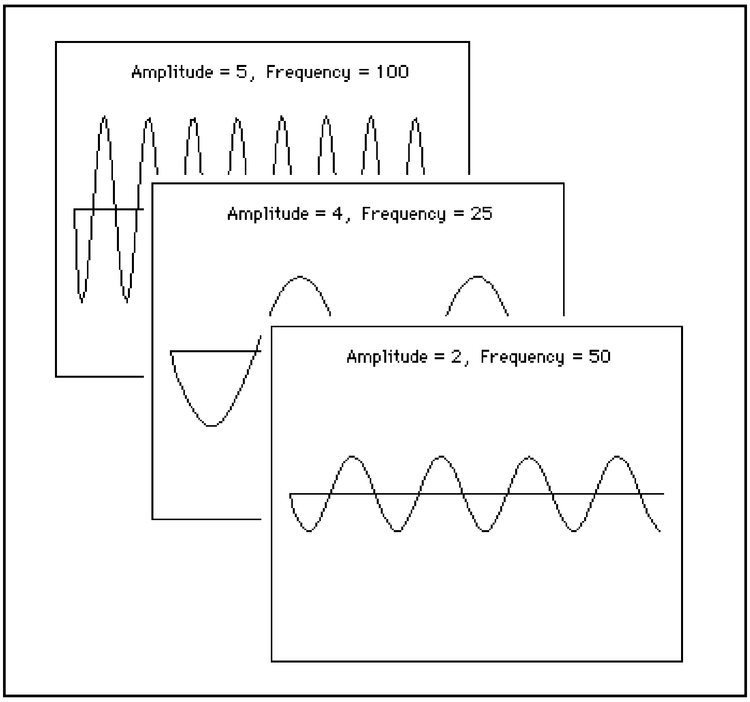

Figure 4: Computer-based experimental study of the effect of changing the amplitude and frequency of a pendulum.

Further experiments become possible when the computer program is modified to include the impact of random or stochastic changes in the amplitude and frequency values that are assumed to take place at each step of the process of model iteration. Figure 5 shows the effect of the random addition of: (a) between 0 and 5 to the value of the amplitude parameter and 0 to 1 to the frequency parameter, and (b) between 0 to 5 to both amplitude and frequency parameters in the computer-based model involving basic amplitude and frequency values of 2 and 25, respectively.

Programming methods other than those that use Pascal are of course available. One such methods uses the principles of systems dynamics and has been implemented in the commercial-of-the-shelf software system called STELLA™ (Richmond, 2001). Figure 6 shows the use of STELLA™ to generate sine and cosine waves with user-selected amplitude and frequency values. Such values (here 3 and 2, respectively) can be selected with the aid of the slider devices provided by the software system (Figure 7). Computed sine and cosine waves, displayed with an arbitrary scale for the time axis, are presented in Figure 8.

The complicated wave forms shown in Figure 5, for example, represent model-based predictions of what would happen if a physical pendulum was subjected to random changes in amplitude and frequency a each time step. Such results would be very difficult to achieve from the study of an actual physical pendulum due to the complexity of the processes of introducing the required random changes in amplitude and frequency in a very rapid manner. However, the development of a computer-based representation of a mathematical model of the pendulum provides an environment where experiments can be undertaken with relative ease. Such computer models can therefore facilitate the development of new levels of understanding of the dynamics of relatively simple physical systems such as an oscillating pendulum. By extension, it is possible to envision the development of computer-based representations of more complex systems, such as societal systems, where performing experiments, or even direct observation of system properties is difficult if not impossible. Such models must be developed and used with care. Some form of validation and verification of models must be undertaken before they could be used to guide operational policy- and decision-making activities where model-based actions could have real implications for the future behavior of human beings in complex societal environments, for example.

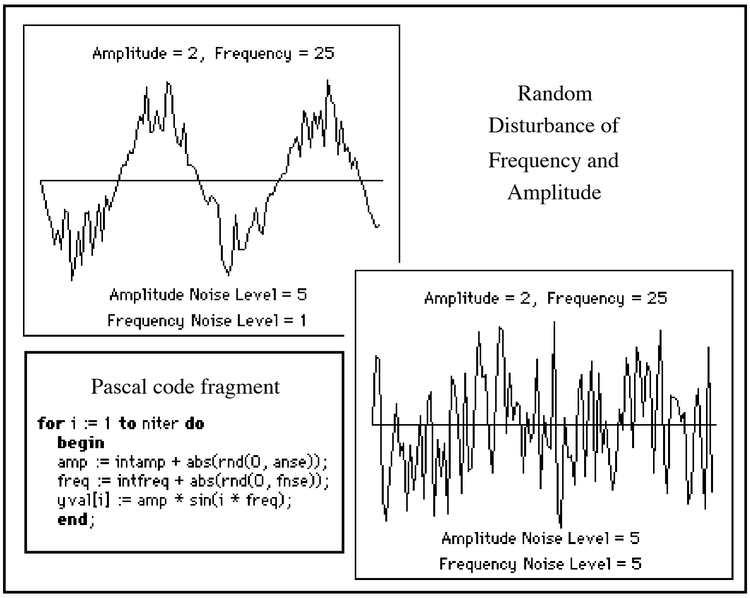

Figure 5: Computer-based experiments studying the impact of random changes in amplitude and frequency on he behavior of a modeled pendulum.

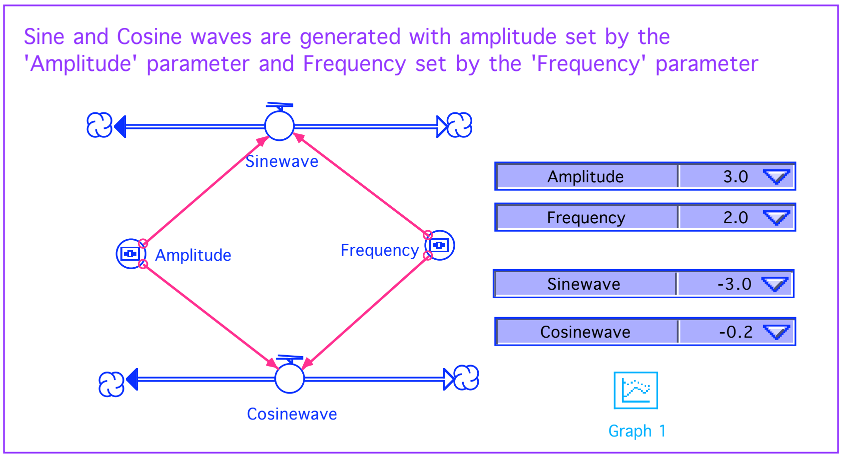

Figure 6: Using STELLA™ to model the behavior of a physical pendulum.

Having provided a brief introduction to some of the principles of model generation and knowledge development, it is now possible to use these principles to study the behavior of several important societal systems. We will begin with a consideration of the role of military and security forces in reducing levels of violence resulting from popular disaffection from a government or ruling elite. A reduction in violence is considered to be necessary to create conditions where stabilization and reconstruction can take place, for example.

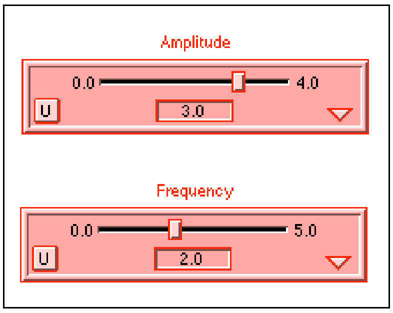

Figure 7: Devices called sliders can define the values of STELLA™ model parameters. Here amplitude and frequency values of 3 and 2 have been selected.

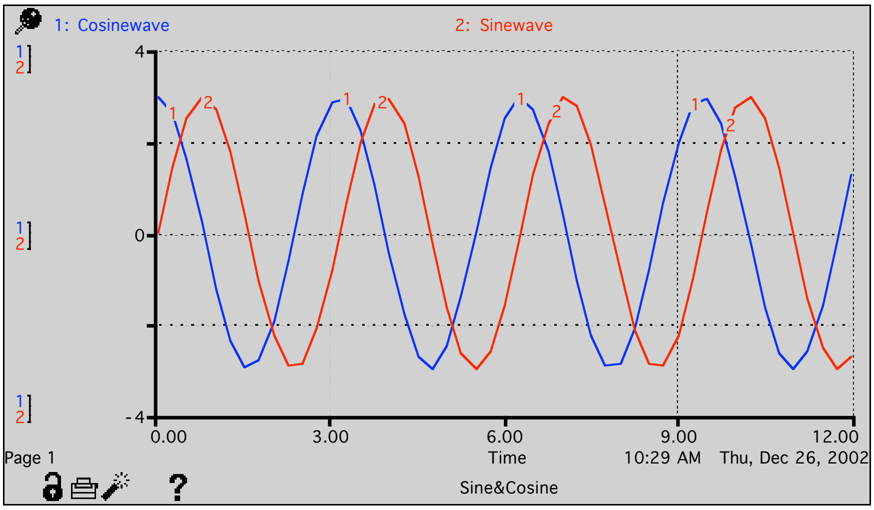

Figure 8: Graphical display of the computed sine and cosine waves.

CASE STUDY I: MILITARY AND SECURITY CONCERNS

The establishment of stable societal conditions depends upon the ability of a government to provide security to an overall population. The first case study presented to the workshop participants used systems dynamics-based principles to examine the destabilizing effects of disaffection and violence and how stability might be achieved by security force actions

DISAFFECTION CAN LEAD TO VIOLENT BEHAVIOR

The models used in this case study are based on the assumption that disaffection can create conditions of potential violence in a society. Actual violence could be generated by appropriate trigger mechanisms. Figure 9 shows a systems dynamics-based representation of those processes. In the model, the number of individuals who have not become disaffected are considered to be members of the group called (Population). Initially the number in that group was set arbitrarily at 1000 for simplicity. Obviously much larger numbers would be involved, what we seek to examine is the overall dynamic behavior rather than the specific umber in an actual population so the use of such numbers is appropriate for illustrative purposes only.

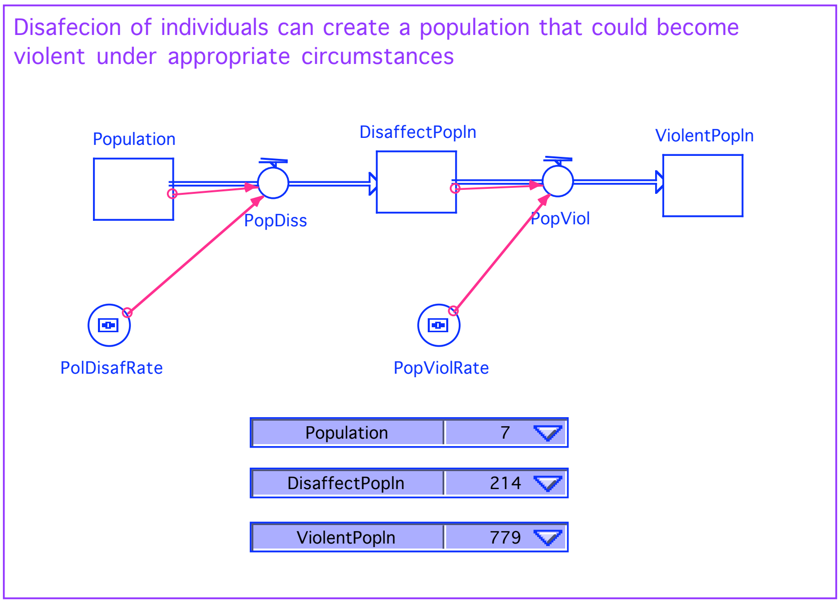

Figure 9: Systems dynamics representation of disaffection and violence creation within a notional society. The rectangular structures are called Reservoirs.

Individuals are assumed to become disaffected at a rate determined by the value of the (PolDisafRate) coefficient. Disaffected individuals can be considered to 'flow into' or join the group of disaffected individuals (DisaffectPopln). A portion of the disaffected individuals are considered to become violent at a rate determined by the value of the (PopViolRate) coefficient. Selection of (PolDisafRate) and (PopViolRate) values can be achieved with the use of slider devices (Figure 10). Selection of (PolDisafRate) = 0.005 and (PopViolRate) = 0.002 represent 0.2 and 0.5 percent of the population becoming disaffected and violent at each time step, respectively. The impact of such movements is shown in Figure 11.

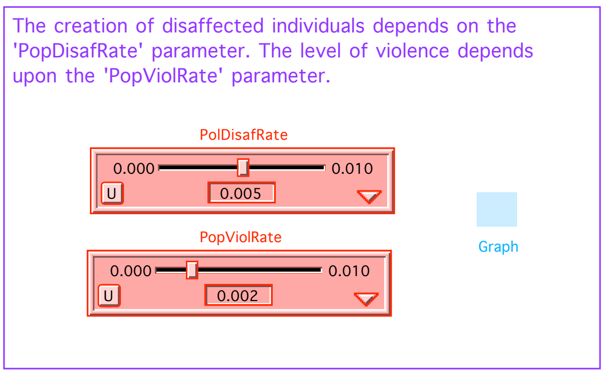

Figure 10: Selection of (PolDisafRate) and (PopViolRate) coefficient values.

The initial size of the non-disaffected population was set at 1000, as mentioned above. With the selected coefficient values, all individuals have become disaffected after some (notional) 600 time steps (Figure 11). The number of disaffected individuals reaches a maximum of just over 500 after 250 time steps and declines as disaffected individuals become violent. The number of violent individuals is still increasing above 750 after 1000 time steps.

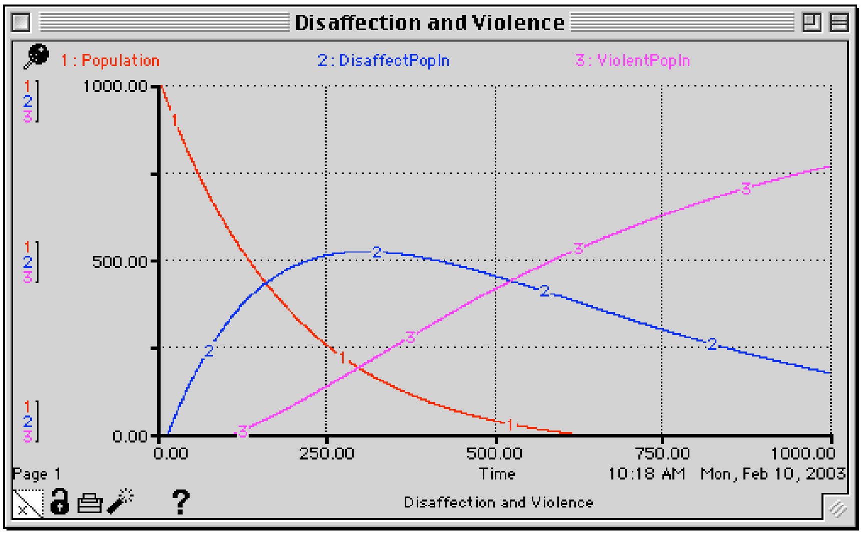

Figure 11: The impact of selection of PolDisafRate = 0.005 and PopViolRate = 0.002 coefficient values on disaffection and violence levels.

SECURITY FORCE ACTION CAN REDUCE VIOLENCE LEVELS

Having explored the dynamics of the processes of disaffection and violence creation with the aid of a simple systems dynamics-based model, it is now possible to enhance that model to examine the impact of security forces in reducing the ability of disaffected individuals to become violent. This would constitute a second cycle of knowledge development (Figure 1). Such an enhancement is shown in Figure 12. In this case, violence suppression, represented by the (ViolSupp) parameter is achieved by the deployment of a proportion (ForceDeploy) of an overall security force (ForceSize). The impact of security force action is assumed to reduce the rate of transfer of individuals from the disaffected to the violent category.

In order to achieve a reduction in the number of disaffected individuals who become violent, the term describing that process was modified from: ((PopViolRt).(DisaffectPopln)) to ((PopViolRt).(DisaffectPopln).(1-(ViolSupp))), where (ViolSupp) is the product of the terms (ForceDeploy) and (ForceSize). Under these circumstances, zero transfer from disaffected to violent would occur when that product was equal to unity. The program was modified to insure that conditions where the product was greater than unity was treated as if the product was actually unity.

With the selected values of (ForceSize) = 40 and (ForceDeploy) = 0.021, the product is 0.84, representing some 84 percent of the maximum security force generated reduction in the transfer from disaffected to violent individuals (Figure 13). Results of the security force intervention are shown numerically in Figure 12 and graphically in Figure 14. After a notional period of 1000 some 7 individuals remain un-disaffected, 743 have become disaffected, and 250 have become violent. Slight differences in the values displayed in Figures 12 and 13 can be attributed to round-off errors.

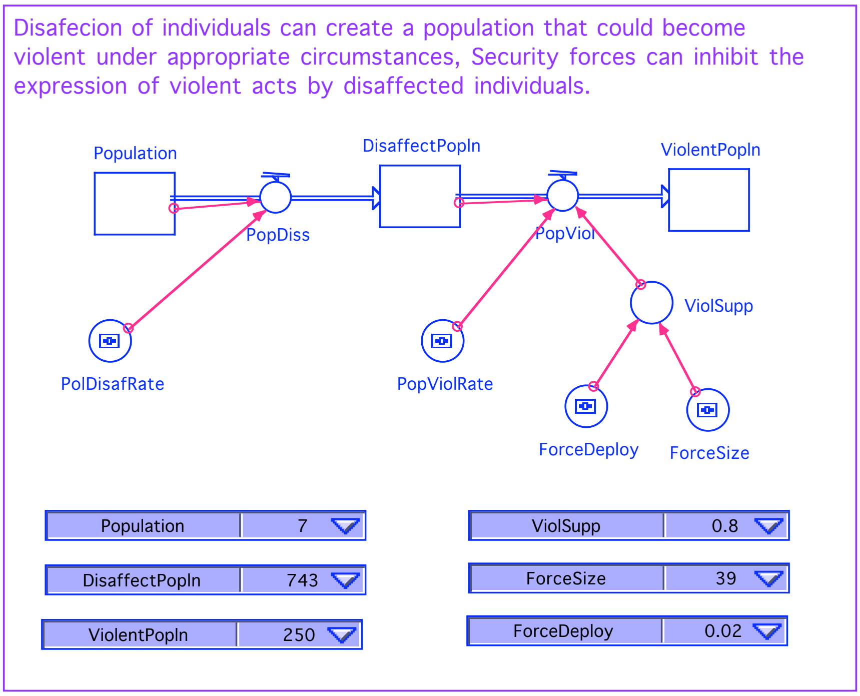

Figure 12: Modeling the impact of a notional security force acting to prevent disaffected individuals from becoming violent.

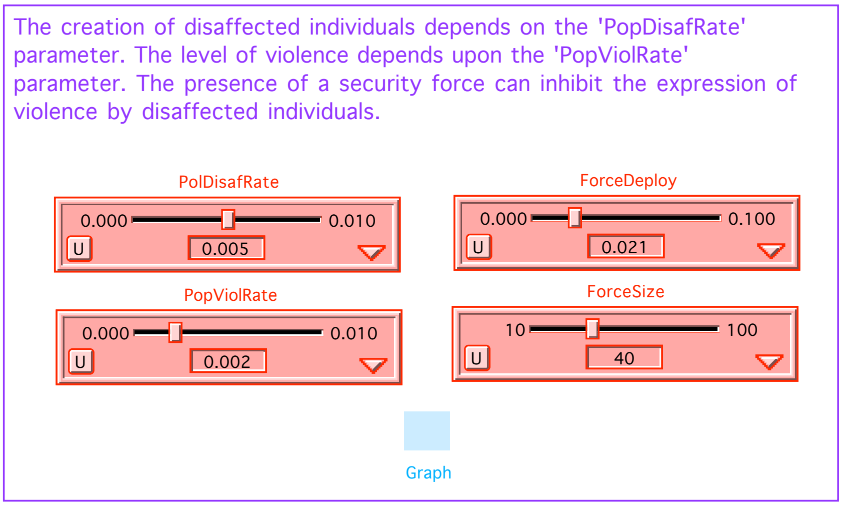

Figure 13: Selection of coefficient values for (PolDisafRate) = 0.005, (PopViolRate) = 0.002, (ForceDeploy) = 0.021, and (ForceSize) = 40.

It is of some interest to compare the results presented in Figures 11 and 14 that show the transfer from individuals disaffected to violent behavior without and with the action of a security force. The first graph shows a large increase in the number of violent individuals.

The second graph shows those individuals being contained as disaffected individuals are denied the ability to become violent. It is expected that a reduction in the level of security force actions would create a rapid transformation of individuals from disaffected to violent, particularly in response to a perceived lack of justice and/or authority for those actions. Such actions could also increase the rate of initial disaffection and the model shown in Figure 12 could be modified to include the effect of security force actions on the overall rate of disaffection, either as a form of back-lash, or representing approval of those actions.

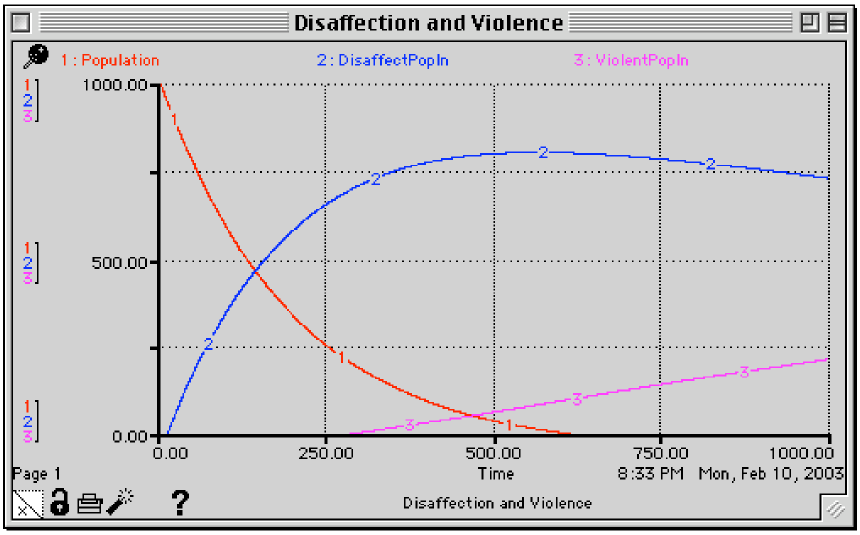

Figure 14: Security force actions produce a significant reduction in violence levels.

IMPACT OF PREEMPTIVE ACTIONS AND SATISFACTION ON DISAFFECTION AND VIOLENCE LEVELS

Information gained from production of the initial models displayed in Figures 9 and 12 can be used to develop a more sophisticated model. Figure 15 shows several such enhancements of these models. In the new model, the needs of at least some of the disaffected individuals are met. In addition, potentially and actually violent individuals are detained by security force action in order to reduce the overall level of violence within the modeled society. In the new model, individuals are assumed to become disaffected at a rate determined by the (Deprivation) coefficient. Some disaffected individuals are assumed to be satisfied by government or other entity actions at a rate determined by the value of the (SupplyNeed) parameter. Satisfied individuals are assumed to re-enter the general, un-disaffected, population at a rate determined by the (Reentrate) coefficient.

Disaffected individuals are assumed to become potentially violent at a rate determined by the (Disaffrate) coefficient. Potentially violent individuals are assumed to become violent at a rate determined by the value of the (Radicalize) coefficient. Potentially violent individuals are assumed to be contained by police at a rate determined by the (Policeact) coefficient. Actually violent individuals are assumed to be contained by military force action at a rate determined by the value of the (Militaryact) coefficient. The model has also been enhanced by facilities that calculate the percentage disaffected (Disaffpct), potentially violent (Potviolpct), and actually violent (Actviolpct) based on the size of the overall population (here assumed arbitrarily to be 1000). One initially disaffected individual was also assumed. Displays are also provided to indicate the actual values of the calculated model parameters. Addition of all individuals is undertaken as a check for the overall computation process.

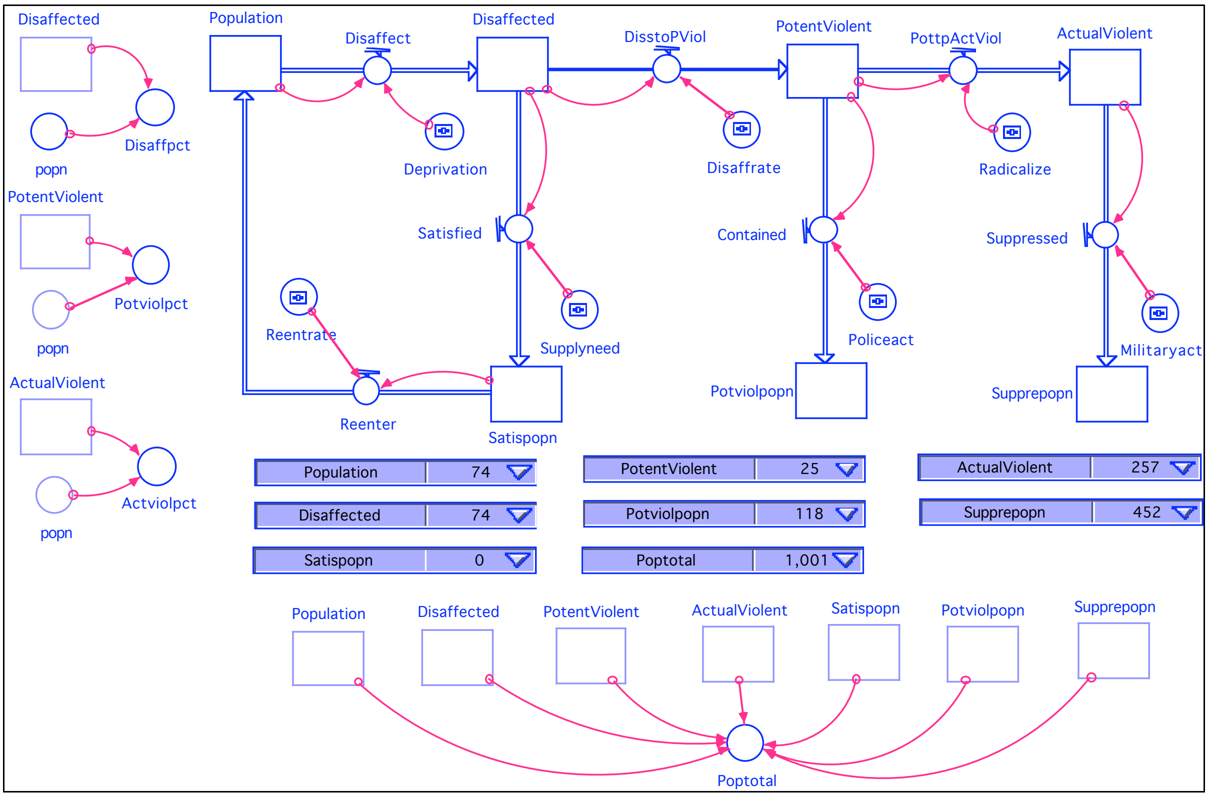

Figure 15: Model-based analyses can assess the effectiveness of violence reduction activities involving attempts at satisfying need as well as preemptive actions involving the incarceration of potentially and actually violent individuals.

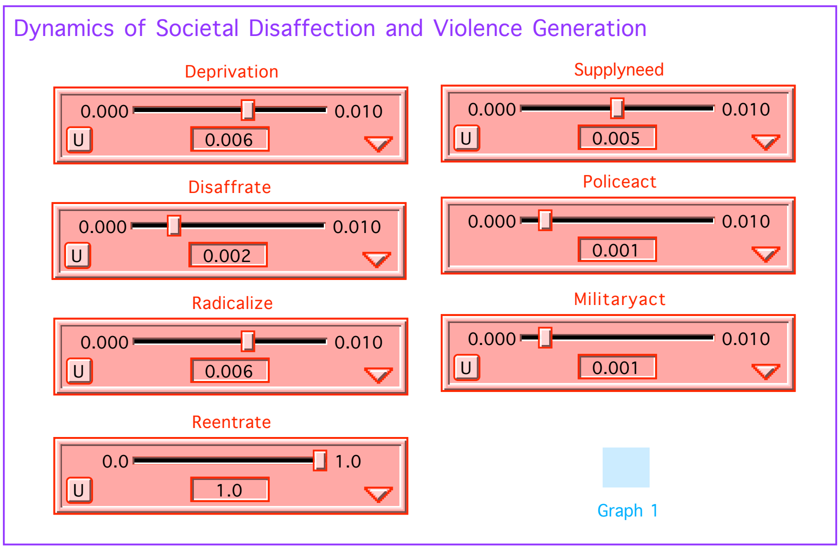

Figure 16: Selection of (Deprivation) = 0.006, (Disaffrate) = 0.002, (Radicalize) = 0.006, (Reentrate) = 1.0, (Supplyneed) = 0.005, (Policeact) = 0.001, and (Militaryact) = 0.001 coefficient values.

The model provides an environment for undertaking a series of studies of the impact of different policies on satisfying need and the removal of potentially and/or actually violent individuals from an overall population. It should be noted that while a particular might indicate what could happen under particular circumstances, the model is not intended to indicate support for any particular policy or decision taken, or not taken, by particular entities whose actions may be described by any particular model. Selected model-generated outputs are shown in Figures 15, 17, 18, and 19.

With selection of the following model coefficient values (Deprivation) = 0.006, (Disaffrate) = 0.002, (Radicalize) = 0.006, (Reentrate) = 1.0, (Supplyneed) = 0.005, (Policeact) = 0.001, and (Militaryact) = 0.001, the pattern of changes in the size of the initial population (Population) (Figure 16), the numbers of disaffected (Disaffected), potentially (PotentViolent), and actually violent (ActualViolent) are shown in Figures 17, 18, and 19. The coeffoicoent values imply that all satisfied individuals immediately re-enter the initial, or un-disaffected, population. (Policeact) and (Miltaryact) coeficient values of 0.001 implies that 0.1 percent of the potentially and actively violent individuals are removed and incarcerated at each time step.

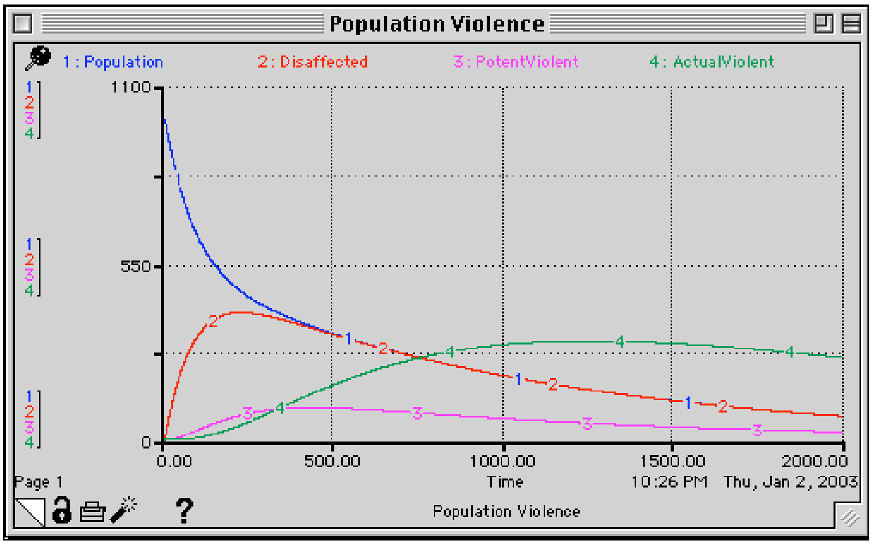

Figure 17: Systems dynamics-based calculation of (Population), (Disaffected), (PotenViolent), and (ActualViolent) values representing the number of un-disaffected, disaffected, potentially violent, and actually violent members of an overall population.

At the end of the modeled 2000 time steps, some 74 remain un-disaffected, 74 individuals are disaffected, 0 are in the satisfied group waiting re-entry into the un-disaffected group (Figure 15). Some 25 individuals are potentially violent and 257 actually violent. 118 potentially violent individuals and 452 actually violent are incarcerated. The total population is 1001 since one individuals was assumed to be disaffected at the outset. Figure 18 shows the significant numbers of disaffected and potentially and actually violent individuals and Figure 19 shows the significant growth in the numbers of individuals in held custody in order to prevent them from becoming violent, or to remove actually violent individuals from the overall population.

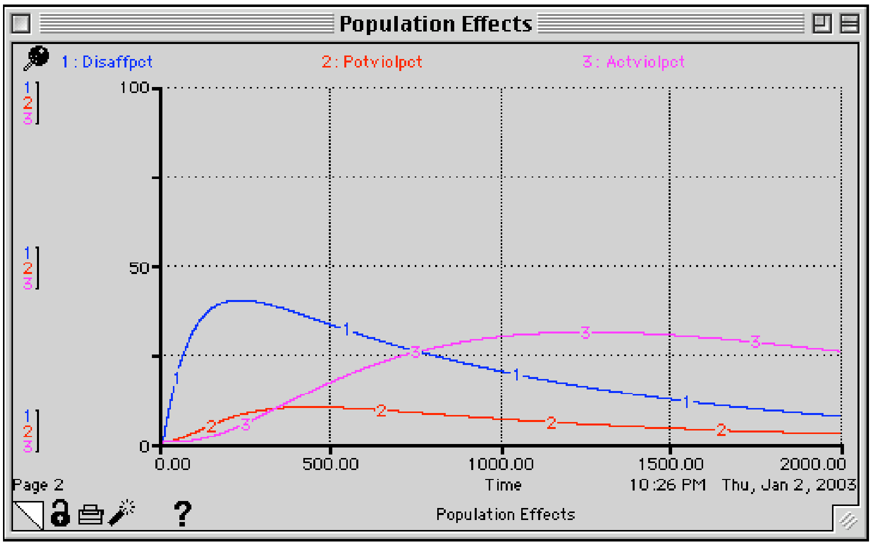

Figure 18: Systems dynamics-based calculation of the percentages of the overall population that are disaffected (Disaffpct), potentially violent (Potviolpct), and actually violent (Actviolpct) individuals.

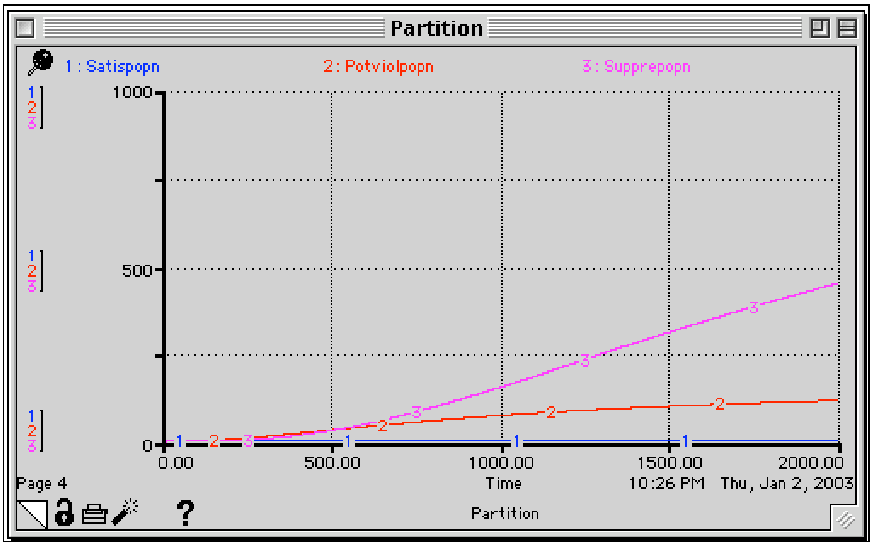

Figure 19: Numbers of the notional population that are satisfied and re-enter the non-disafffected population (Satispopn), excluded and prevented from becoming violent (Potviolpopn), and excluded individuals that had become violent (Supprepopn).

The model illustrated in Figure 15 provides a notional representation of the possible effect of disaffection creating potentially and actually violent individuals and of the impact of different policies aimed at reducing disaffection and violence. In the use of the model described in Figures 15 to 19, a process of need satisfaction promoting the re-entry of newly satisfied individuals into the overall un-disaffected population is assumed to take place against a background of preventative detention and detention of actually violent individuals. It is clear that such detention could be an actual cause of disaffection and would counteract attempts to provide satisfaction of disaffected individuals.

It is clear that other processes involving religious, ethnic, political, financial and other influences resulting in changes in the relative numbers of satisfied, dissatisfied, potentially and actually violent individuals. Such processes could be included in a more elaborate model developed in subsequent cycles of the knowledge development processes. Some form of model validation and verification would have to be undertaken before any model could be used to guide actual policy- and/or decision-making and other activities.

CASE STUDY II: DISARMAMENT, DEMOBILIZATION, AND RE-INTEGRATION (DD&R)

The second case study is concerned with the processes of disarmament, demobilization, and reintegration (DD&R) whereby individuals previously involved in combat are transformed from combat fighters to individuals whose focus is assumed to be more on involvement in civilian activities in an overall society. Such activities can be more or less successful and may create relatively long periods of tranquility involving or may serve as a precursor for additional conflict. Several approaches have been adopted to undertake the DD&R process. One of these processes (which is referred to as Restricted DD&R) involves the relative or complete isolation of individuals undergoing the DD&R process from the overall population, and their re-entry into that population after such isolation. Another activity (which is referred to as Unrestricted DD&R) attempts to undertake DD&R when the individuals undergoing those activities remain exposed to the overall population. Two systems dynamics-based models have been produced n attempt to examine the effectiveness of Restricted and Unrestricted DD&R processes in de-militarizing combatants and promoting their re-entry to a wider civilian society.

THE RESTRICTED DD&R PROCESS

An initial systems dynamics-based model representation of a Restricted DD&R process is shown in Figure 20. In this model, combatants (Combatants) are disarmed at a rate determined by the value of the (Entryrate) coefficient. Disarmed individuals (Disarm) are demobilized at a rate determined by the (Demobrate) coeffient. Demobilized individuals (Demob) re-enter the overall society (Reintegrt) at a rate determined by the (Reintrate) coefficient. New reservior-like structures are introduced in this model. Demobilization is assumed to involve an ‘Oven’ construct, where individuals remain for a user-selected time. Reintegration is assumed to involve a ‘first-in first out’ ‘Conveyer’ processes. Use of these processes is aimed at insuring isolation of DD&R participants.

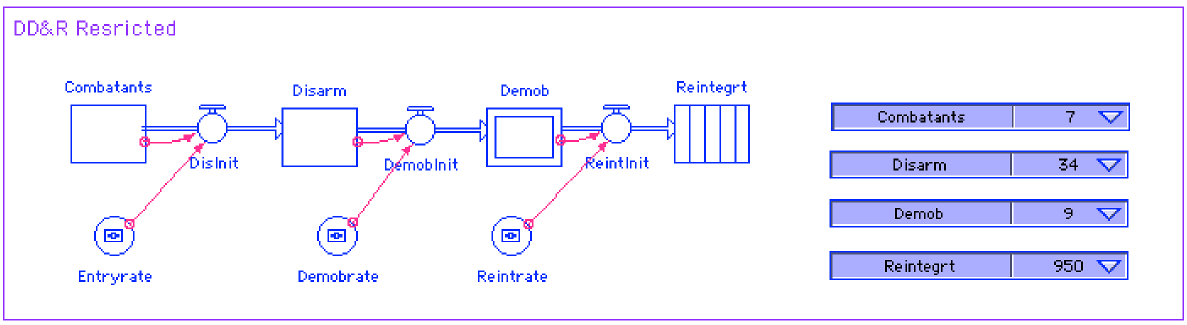

Figure 20: Restricted DD&R prevents loss of individuals from the overall process.

Results of model-based calculations with selection of the following coefficient values (Entryrate) = 0.005, (Demobrate) = 0.005, and (Reintrate) = 0.002 (Figure 21) is shown in Figures 20 and 22. In this case, some 7 combatants have not begun the DD&R process out of an initial notional 1000 individuals after a notional 1000 time steps. Some 34 individuals are in the disarmament process, 9 are undergoing demobilization, and 950 have been reintegrated into the wider society. (Figure 20).

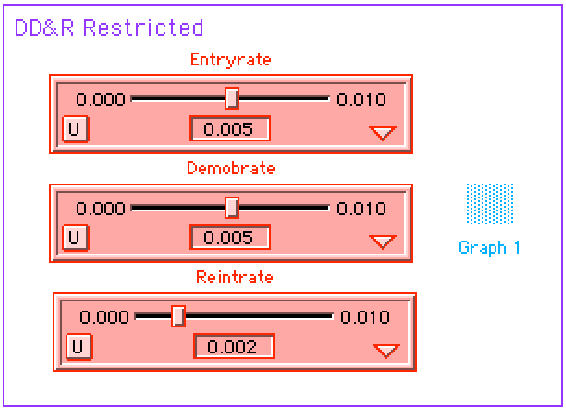

Figure 21: Selection of the (Entryrate) = 0.005, (Demobrate) = 0.005, and (Reintrate) = 0.002 coefficient values.

The 'saw-tooth' profile of the (Demob) graph shown in Figure 22 is a result of the properties of the oven-like reservoir activity. In that activity, a user-selected number of entities enter the oven reservoir, remain in that environment for a user-selected interval, and then leave. In the DD&R model, it was assumed that up to 100 individuals could enter the modeled demobilization processes. That process was assumed to last for some 50 time steps. It is evident that selection of different capacities and duration (reflecting different capabilities of the overall demobilization process) would generate different through-puts of demobilized individuals.

The stair-step profile of the (Reintegrt) graph in Figure 22 reflects the release of demobilized individuals into the overall population at 50 time step intervals from the ('oven'-based) demobilization process. The initial Restricted DD&R model described in Figure 20 provides the basis for other models of that process. An enhanced model could include multiple disarmament and demobilization activities working in parallel at different locations and at different capacity and throughput rates. A more inclusive overall model might include both Restricted and Unrestricted DD&R activities and assume that individuals undergoing Restricted DD&R processing might be less (or, perversely, perhaps more!) likely to revert to military actions in the face of increasing deprivation and disaffection, for example.

UNRESTRICTED DD&R PERMITS LOSS OF INDIVIDUALS AT THE DISARMAMENT, DEMOBILIZATION, AND REINTEGRATION STAGES

The process of Unrestricted DD&R is assumed to involve disarmament, demobilization, and reintegration of former combatants while they remain in contact with other former combatants not involved in DD&R as well as individuals in the society within which the process is being undertaken. Figure 23 shows an initial model of the Unrestricted DD&R process that is based on the use of reservoir processes and without specialized 'oven' and 'conveyor' processes.

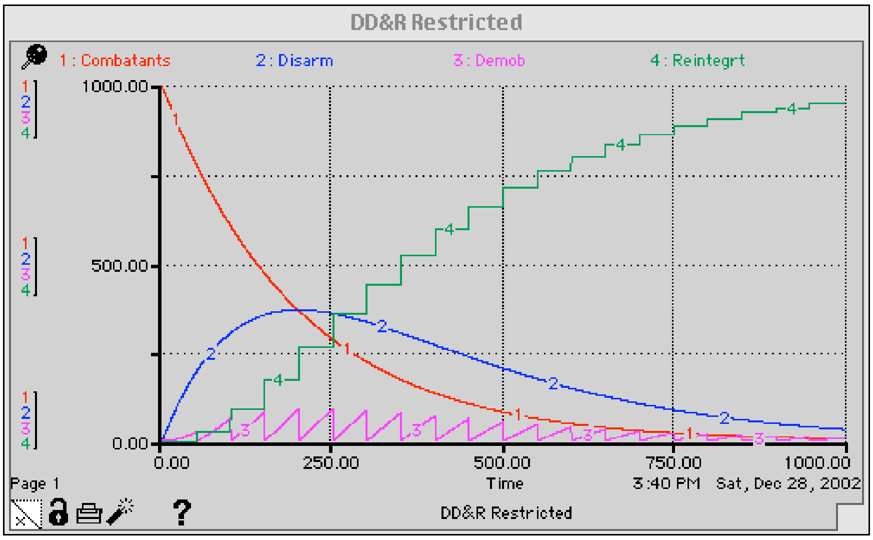

Figure 22: Restricted DD&R prevents loss of individuals from the overall process.

In the case of unrestricted DD&R, individual ex-combatants (Combatants2) are disarmed at a rate determined by the value of the (Entryrate2) coefficient and become disarmed (Disarm2). Disarmed individuals are demobilized (Demob2) at a rate determined by the (Demobrate2) parameter. Individuals are assumed to reenter (Reintegrt2) the overall population at a rate determined by the (Reinterate2) coefficient. In parallel with those activities, access to the combatant pool of non-DD&R processed individuals is assumed to lead to a loss of individuals from the overall DD&R process during disarmament phase at a rate determined by the (DisLosrt) coefficient. Individuals are assumed to be lost from the demobilization activity at a rate determined by the (DemobLosrt) coefficient and from the reintegration activity at a rate determined by the (ReintLosrt) coefficient.

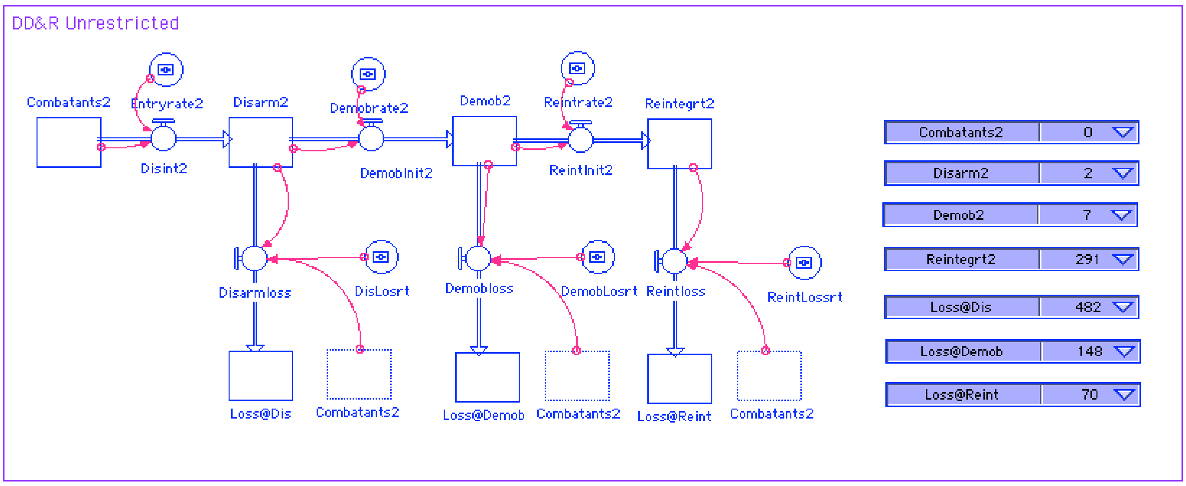

Figure 23: Systems dynamics-based model of the process of unrestricted DD&R in which loss is caused interaction between ex-combatants not yet involved in the processes and individuals involved in components of the process.

Results obtained from use of the Unrestricted DD&R model to calculate changes in the values of the (Combatants2), (Disarm2), (Demob2), (Reintegrt2), and (Combatants2), (Loss@Dis), (Loss@Demob), and (Loss@Reint) model parameters for the following values of the model coefficients: of (Entryrate) = 0.008, (Demobrate2) = 0.008. (Reintrate) = 0.008. (DisLosrt) = 0.00029, (DemobLosrt) = 0.00028, and ReintLosrt) = 0.00018 coefficient values. are shown in Figures 23, 25, and 26. With these settings, after some 1000 time steps have elapsed, no individuals of the initial 1000 remain as combatants. Two individuals are in the (Disarm2) category, and 7 are in the (Demob2) category. A total of 291 have entered the (reintegrt2) category. Some 482 individuals were lost at the disarmament step (Loss@Dis), 148 were lost at demobilization (Loss@demob), and 70 were lost at the reintegration step (Loss@Reint).

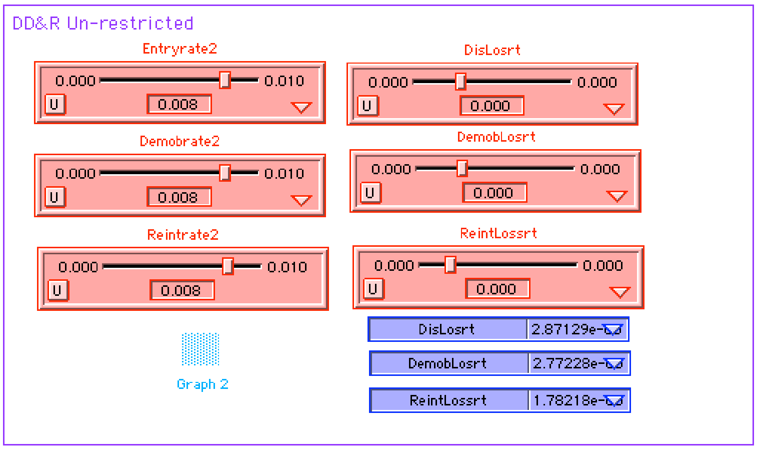

Figure 24: Selection of (Entryrate) = 0.008, (Demobrate2) = 0.008. (Reintrate) = 0.008. (DisLosrt) = 0.00029, (DemobLosrt) = 0.00028, and ReintLosrt) = 0.00018 coefficient values.

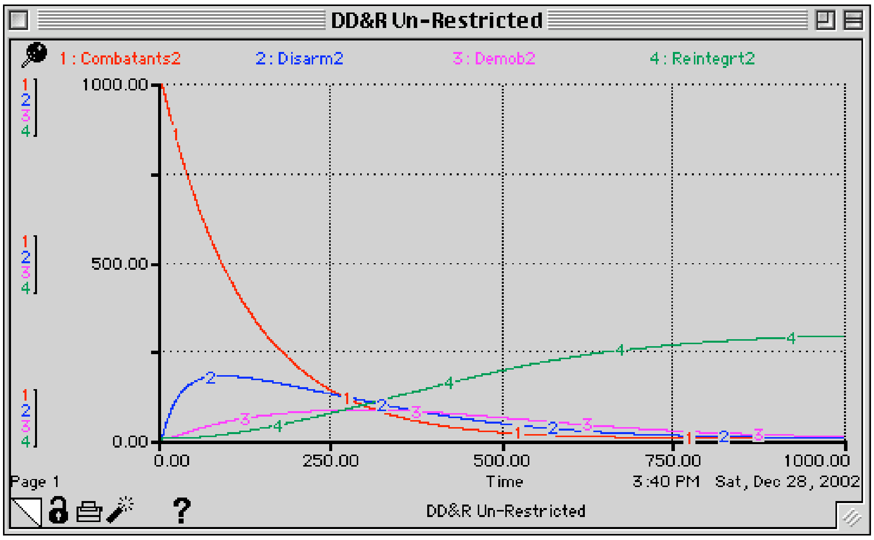

Figure 25: Patterns of change in the values of the (Combatants2), (Disarm2), (Demob2), and (Reintegrt2) parameters.

This initial model of the process of Unrestricted DD&R provides the basis for the development of more sophisticated models which include additional factors. Of interest in this context is the inclusion of the representation of the effect of the treatment of reintegrated individuals on their propensity to take up arms again under appropriate circumstances. A fusing of elements of the model of societal disaffection and the creation of potentially or actually violent individuals would also appear to be appropriate. An enhanced model could include the retraining of former combatants and their recruitment into national military, security, and/or police forces. Additional enhancements might include representations of the influence of established or emerging political and/or religious organizations in defining areas of conflict which might engage the participants in the DD&R process, for example.

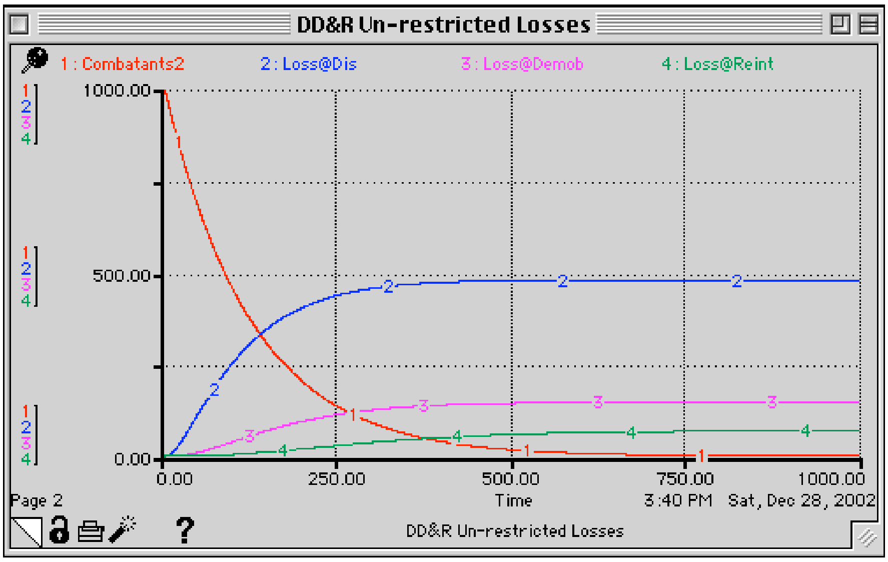

Figure 26: Patterns of change in the (Combatants2), (Loss@Dis), (Loss@Demob), and (Loss@Reint) model parameters.

CASE STUDY III: HUMANITARIAN RELIEF AND PUBLIC HEALTH

The third case study focussed on the production of simple systems dynamics-based models of the process of the infection by and recovery from infectious diseases. The simple model will then be enhanced to include a representation of the impact of public health and medical care on the spread of and recovery from disease.

A BASIC DISEASE MODEL INVOLVES INFECTION, RECOVERY, AND MORTALITY

The basic model of the disease process shown in Figure 27 is representative of general models of such processes (Bailey, 1957; Murray, 1993; and Thomas, 1992; for example). In the model an initial 1000 susceptible individuals (Suscept) become infected (initial number 1) at a rate determined by the (InfectRate) coefficient. Infected individuals (Infect) either recover at a rate detemined by the value of the (RecovRt) coefficient or die (Death) at a rate determined by the (MortRte) coefficient. Selection of the following model coefficient values: (InfectRte) = 0.0001, (RecovRt) = 0.007, and (MortRte) = 0.001 (Figure 28) generates the results displayed in Figures 27 and 29. Of an initial 1000 individuals, none remain susceptible and uninfected after 1000 time steps have passed. One individual remains infected, 875 have recovered, and 125 have died. The infection appears to be noticeable after some 50 time steps, and to be essentially over after 500 time steps, with some additional recovery and deaths taking place during the next 500 time steps.

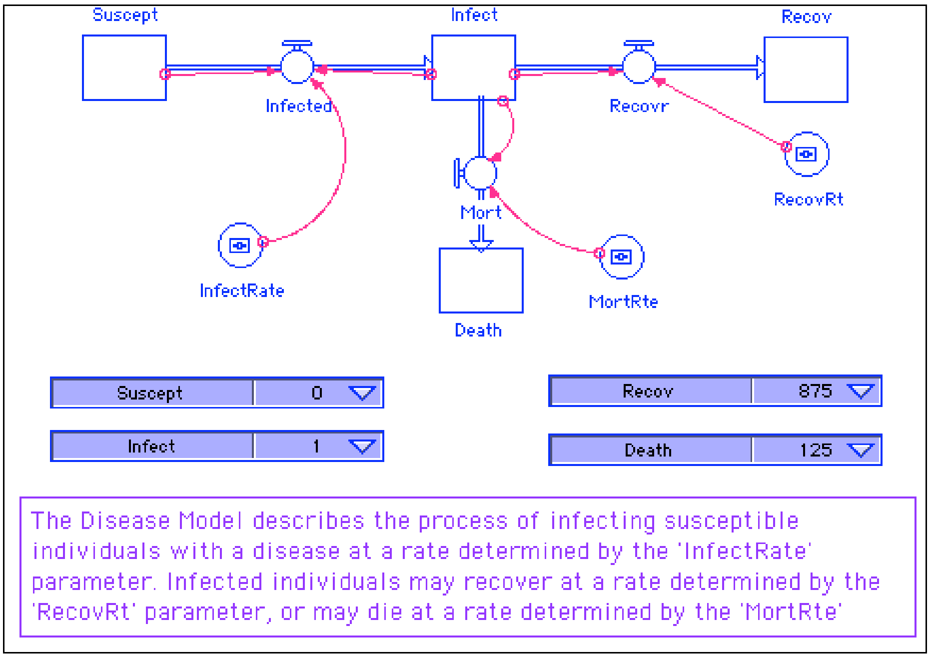

Figure 27: A basic disease model represents the infection and subsequent recovery or death of susceptible individuals at rates that depend on user-selectable model coefficient values.

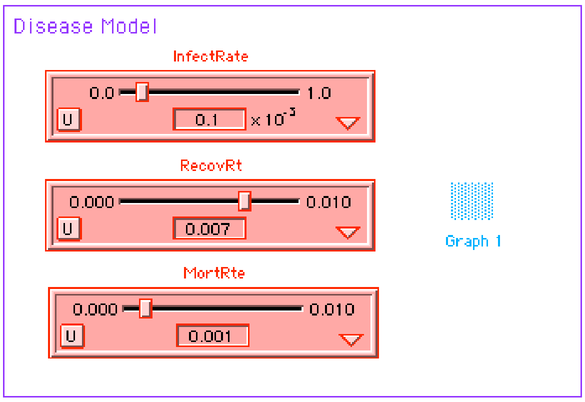

Figure 28: Selection of the (InfectRte) = 0.0001, (RecovRt) = 0.007, and (MortRte) = 0.001 model coefficient values.

AN ENHANCED DISEASE MODEL CAN MODEL THE IMPACT OF PUBLIC HEALTH AND MEDICAL CARE

The basic disease model shown in Figure 27 can be modified to include the impact of both public health and medical care processes in determining the outcome of a disease infection.

Such enhancements are presented in Figure 30. In this case, medical care has been introduced as a process that is intended to facilitate the recovery of infected individuals, Public health processes, by contrast, are assumed to act to reduce the likelihood of the infection of susceptible individuals. The impact of the medical care and public health processes are determined by the selected values of the (MedicalEfft) and (PubHlth) coefficient values.

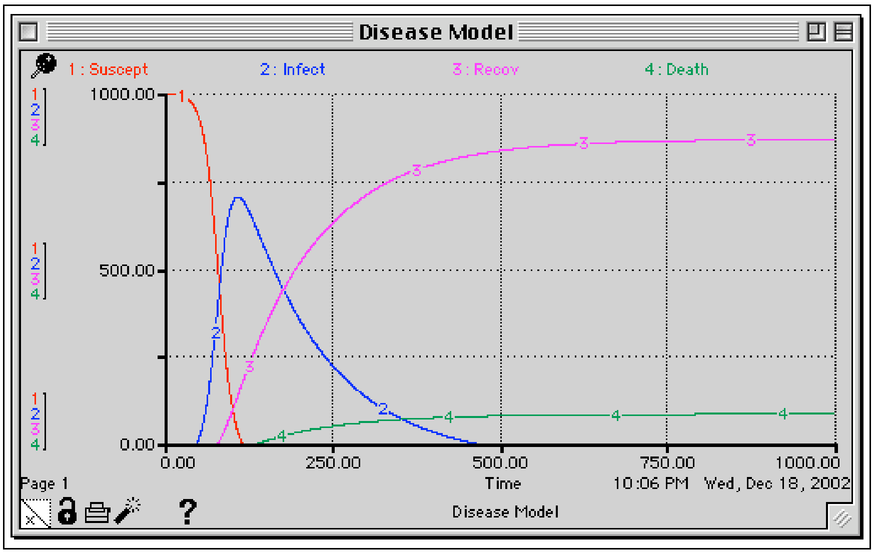

Figure 29: Time-dependent behavior of the basic disease model involving Infection, Recovery, and Death.

Results obtained from use of the following model coefficient values (InfectRate) = 0.0003, (RecovRt) = 0.005, (MortRte) = 0.0001, (MedicalEfft) = 0.01, and (PubHlthEfft) = 0.0002 are shown in Figures 30, 32, 33, and 34. Common values for (InfectRate), (RecovRt), and (MortRte) were selected for all three models (Figure 30).

1. Basic disease model: The basic disease model without additional medical care or public health activities shows that none of the 1000 initially susceptible individuals remains to be infected (initial number = 1) after 1000 time steps. Of the 1000 individuals, 88 remain infected, 895 have recovered, and 18 have died. Figure 32 shows the time-dependent behavior of the components of the basic disease model and reveals the significant number of individuals who have not recovered after the 1000 time step period of model execution.

2. Basic disease model with medical care: Involvement of medical care with selection of the (MedicalEfft) coefficient = 0.01 leads to model-generated results that indicate no susceptible individuals remain to be infected. The calculated numbers of infected, recovered, and dead individuals are 1, 994, and 7, respectively. Recovery facilitated by medical care appears to have reduced the number of individuals who might otherwise have died from the notional disease. It is evident that the addition of medical care to the overall model causes an overall speeding-up of the recovery process (Figure 33).

3. Basic disease model with medical care and public health services: Addition of a model of the impact of public health is shown in Figure 30. Selection of the (PubHlthEfft) = 0.0002 creates conditions in which one susceptible individual

has not been infected. Calculated numbers of infected, recovered, and dead individuals are 2, 991, and 7, respectively. The major dynamical impact of the public health intervention, shown in Figure 34 is the introduction of a significant delay in the process of infection, which appears to be noticeable after some 40-50 time steps (Figure 34) compared with 10-20 in the basic model (Figure 32).

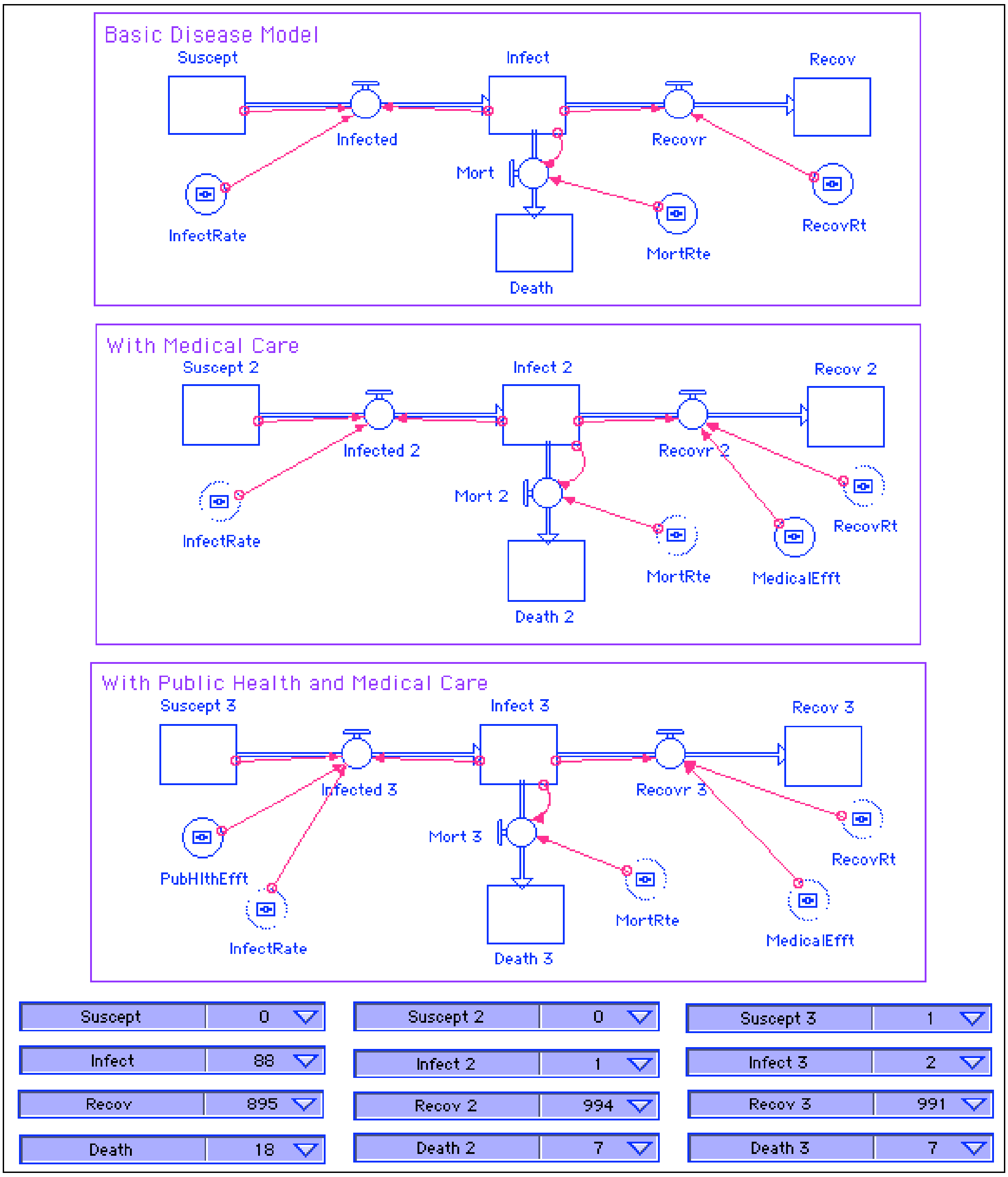

Figure 30: The impact of medical care and public health services on disease outcomes involving infection, recovery, and mortality processes.

It is interesting to note the relatively much smaller value of the selected (PubHlthEfft) coefficient = 0.0002 coefficient compared with the (MedicalEfft) = 0.01. This might be interpreted as providing some support for the assertion of the important role of prevention of the initial spread of a disease compared with the potentially more complicated and expensive actions of providing medical care to infected individuals. Clearly this matter should be the focus of further model-building and analysis activities.

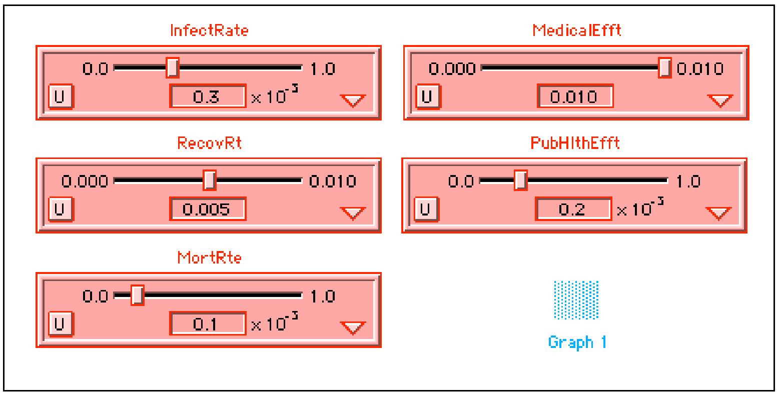

Figure 31: Selection of the (InfectRate) = 0.0003, (RecovRt) = 0.005, (MortRte) = 0.0001, (MedicalEfft) = 0.01, and (PubHlthEfft) = 0.0002 model coefficient values.

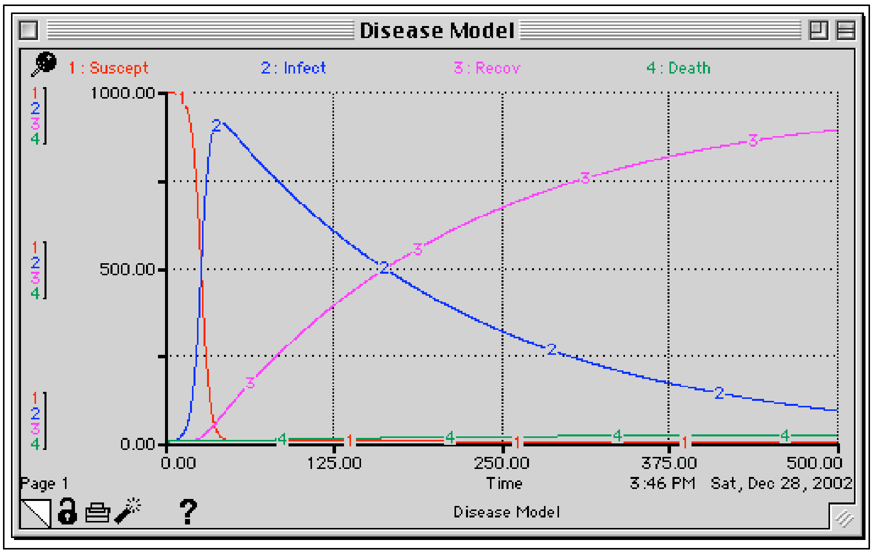

Figure 32: Model-generated output for the basic disease model for the (Suscept), (Infect), (Recov), and (Death) parameters. Note the relatively slow recovery compared with the results produced by the other models.

The basic disease model described above is based on the principles used to construct other disease models described in the literature (Bailey, 1957 and Murray, 1993, for example). It serves as an introduction to disease dynamics, and should be used with care. No actual disease is represented and outcome from the model should not be used in any way whatsoever to guide the study of or the response to actual diseases. The use of any model for such purposes should only take place after appropriate validation and verification activities have been undertaken.

The addition of models of public health and medical care processes has provided models that might be used to assess the relative effectiveness of those processes in determining the magnitude and duration of a disease outbreak. Use of epidemiological and other data relating to the characteristics of actual diseases could result in the development of an enhanced model of the dynamics of infection, recovery, and mortality associated with those diseases. Development of much more sophisticated representations of public health and medical care processes is obviously necessary in order to include details of actual processes of those types. Furthermore, since the processes of infection, recovery, and death from a disease take place in both time and space, models that represent spatially-dependent processes are clearly needed. Spatial dynamics can be represented only with great difficulty, and then only partially, by systems dynamics models. Additional modeling techniques involving the use of intelligent automata have been developed and used by Cobb and Woodcock for such purposes, but description of those models is outside the scope of this paper.

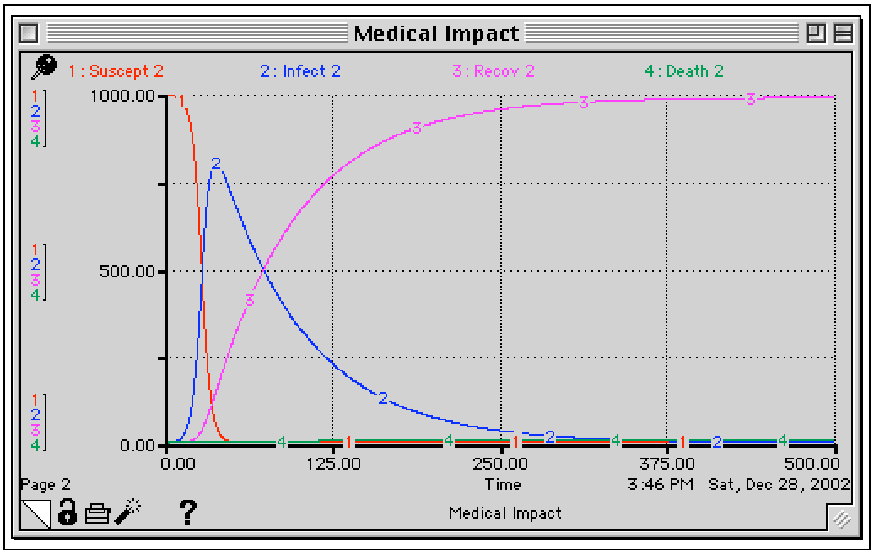

Figure 33: Model-generated output showing the impact of medical care on the (Suscept2), (Infect2), (Recov2), and (Death2) parameters. Note the relatively rapid recovery compared with the results produced by the basic disease model.

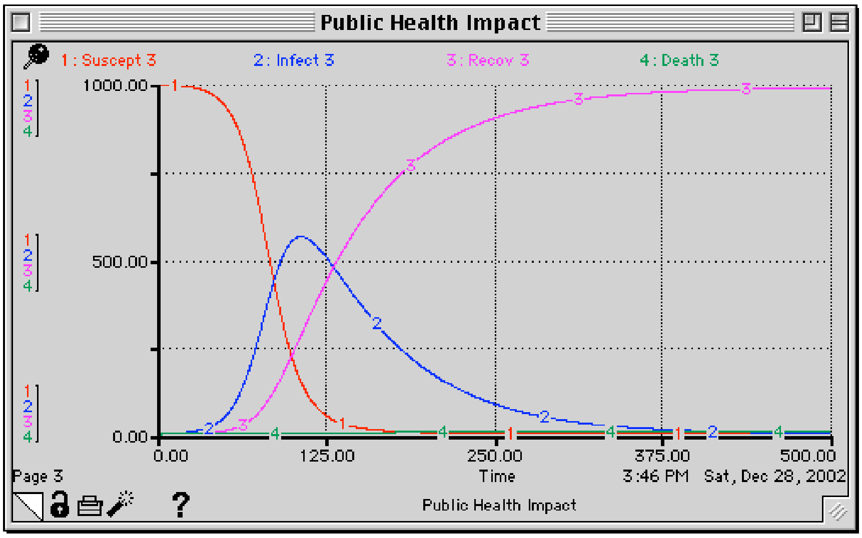

Figure 34: Model-generated output showing the impact of medical care and public health on the (Suscept3), (Infect3), (Recov3), and (Death3) parameters. Note the relatively late onset of infection and rapid recovery compared with the results produced by the basic disease model.

CASE STUDY IV: REFUGEES AND DISPLACED PERSONS

The fourth case study focussed on use of a systems dynamics model implemented in STELLA™ that had been developed and implemented in another software system by Davis (personal communication). The author is most grateful for Davis' permission to use his model for the basis of the case study reported in this paper. Davis developed a model of the processes of refugee resettlement of Serb, Bosnian, and Croatian Refugees in Bosnia involving displaced persons, internally displaced persons, and refugees. Davis enhanced the initial model to take into account the disturbance of previously-settled refugees and the creation of a new group of internally-displaced persons. It is that enhanced model that will be used as the basis of the studies described below. Three related models were created, one each for the Serbian, Croatian, and Bosnian populations of Bosnia-Herzegovina (Figures 35, 36, and 37). Results obtained from the use of those models are presented below.

THE SERBIAN REFUGEE RESETTLEMENT MODEL

Figure 35 shows the Serbian refugee resettlement model. In this case Serbian refugees (SbRef) are assumed to be resettled directly at a rate dependent upon the value of the (SbRrr) coefficient, or to enter an intermediate displaced persons/internally displaced persons status (SbRIDPDP) at a rate determined by the coefficient (SbRelosr). Those individuals were assumed to become either displaced persons outside Bosnia proper (SbDP) at a rate dependent on the coefficient (SbReDPrr), or internally-displaced individuals (SbIDP) at a rate dependent on the coefficient (SbReIDPrr). Displaced (SbDP) and internally-displaced (SbIDP) individuals were assumed to be resettled at rates dependent upon the coefficients (SbDPrr) and (SbIDPrr), respectively. In addition, new internally-displaced individuals (SbNewIDP) were assumed to be created at a rate dependent upon the (Sb2Loss) coefficient.

Initial values of the different components of the total notional Serbian refugee-related population set arbitrarily at 30,000, were set at the following values: (SbRef) = 5000, (SbRIDPDP) = 0, (SbDP) = 10000, (SbIDP) = 15000, (TotsetSb) = 0, and (SbNewIDP) = 0. Model coefficients were set at the following values: (SbRrr) = 0.001 (reflecting a 0.1 per cent return at each time step), (SbRelosr) = 0.001, (SbReDPrr) = 0.001, (SbReIDPrr) = 0.002, (SbDPrr) = 0.01, (SbIDPrr) = 0.005, and (Sb2Loss) = 0.0 (Figure 38). Model-generated results are shown in Figures 35, 39, and 42. After a notional period of 1000 time steps, the sizes of the different components of the overall Serbian population are as follows: (SbDP) = 49, (SbRef) = 676, (SbIDP) = 314, (SbRIDPDP) = 428, (TotsetSb) = 28,532, and (SbNewIDP) = 0. The dynamics of the Serbian resettlement process indicate an increasing level of resettlement (Figures 39) without the creation of new internally-displaced individuals (Figure 42).

THE CROATIAN REFUGEE RESETTLEMENT MODEL

Figure 36 shows the Croatian refugee resettlement model. In this case Croatian refugees (CrRef) are assumed to be resettled directly at a rate dependent upon the value of the (CrRrr) coefficient, or to enter an intermediate displaced persons/internally displaced persons status

(CrRIDPDP) at a rate determined by the coefficient (CrRelosr). Those individuals were assumed to become either displaced persons outside Bosnia proper (CrDP) at a rate dependent on the coefficient (CrReDPrr), or internally-displaced individuals (CrIDP) at a rate dependent on the coefficient (CrReIDPrr). Displaced (CrDP) and internally-displaced (CrIDP) individuals were assumed to be resettled at rates dependent upon the coefficients (CrDPrr) and (CrIDPrr), respectively. In addition, new internally-displaced individuals (CrNewIDP) were assumed to be created at a rate dependent upon the (Cr2Loss) coefficient.

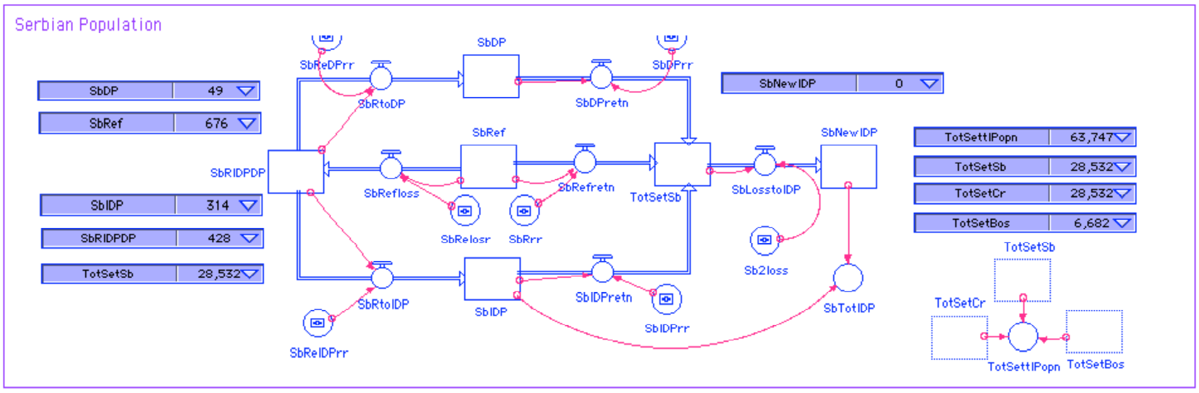

Figure 35: A model of Serbian refugee settlement modified to account for the re-displacement of initially re-settled refugees (modified after Davis).

Initial values of the different components of the total notional Croatian refugee-related population set arbitrarily at 30,000, were set at the following values: (CrRef) = 5000, (CrRIDPDP) = 0, (CrDP) = 10000, (CrIDP) = 15000, (TotsetCr) = 0, and (CrNewIDP) = 0. Model coefficients were set at the following values: (CRrr) = 0.001 (reflecting a 0.1 per cent return at each time step), (CrRelosr) = 0.001, (CrReDPrr) = 0.001, (CrReIDPrr) = 0.002, (CrDPrr) = 0.01, (CrIDPrr) = 0.005, and (Cr2Loss) = 0.0 (Figure 38). Model-generated results are shown in Figures 36, 40, and 43. After a notional period of 1000 time steps, the sizes of the different components of the overall Croatian population are as follows: (CrDP) = 49, (CrRef) = 676, (CrIDP) = 314, (CrRIDPDP) = 428, (TotsetCr) = 28,532, and (CrNewIDP) = 0. The dynamics of the Croatian resettlement process indicate an increasing level of resettlement (Figure 40) without the creation of new internally-displaced individuals (Figure 43).

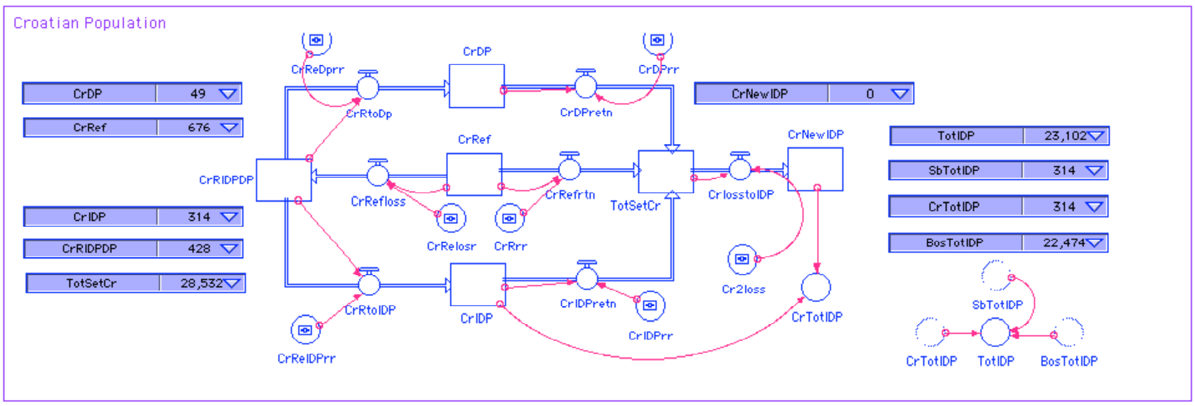

Figure 36: A model of Croatian refugee settlement modified to account for the re-displacement of initially re-settled refugees (modified after Davis).

THE BOSNIAN REFUGEE RESETTLEMENT MODEL

Figure 37 shows the Bosnian refugee resettlement model. In this case Bosnian refugees (BosRef) are assumed to be resettled directly at a rate dependent upon the value of the (BsRrr) coefficient, or to enter an intermediate displaced persons/internally displaced persons status (BosRIDPDP) at a rate determined by the coefficient (BsRelosr). Those individuals were assumed to become either displaced persons outside Bosnia proper (BosDP) at a rate dependent on the coefficient (BsReDPrr), or internally-displaced individuals (BosIDP) at a rate dependent on the coefficient (BsReIDPrr). Displaced (BosDP) and internally-displaced (BosIDP) individuals were assumed to be resettled at rates dependent upon the coefficients (BsDPrr) and (BsIDPrr), respectively. In addition, new internally-displaced individuals (BosNewIDP) were assumed to be created at a rate dependent upon the (Bos2Loss) coefficient.

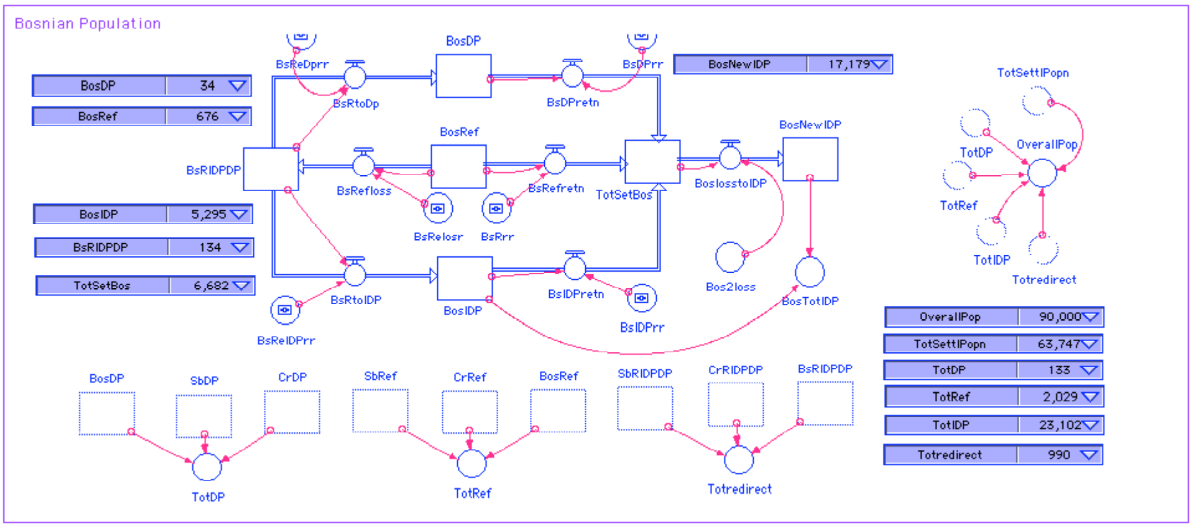

Figure 37: A model of Bosnian refugee settlement modified to account for the re-displacement of initially re-settled refugees (modified after Davis).

Initial values of the different components of the total notional Bosnian refugee-related population set arbitrarily at 30,000, were set at the following values: (BosRef) = 5000, (BosRIDPDP) = 0, (BosDP) = 10000, (BosIDP) = 15000, (TotsetBos) = 0, and (BosNewIDP) = 0. Model coefficients were set at the following values: (BsRrr) = 0.001 (reflecting a 0.1 per cent return at each time step), (BsRelosr) = 0.001, (BsReDPrr) = 0.002, (BsReIDPrr) = 0.005, (BsDPrr) = 0.01, (BsIDPrr) = 0.001, and (Bos2Loss) = 0.002 (Figure 38). Model-generated results are shown in Figures 37, 41, and 44. After a notional period of 1000 time steps, the sizes of the different components of the overall Serbian population are as follows: (BosDP) = 34, (BosRef) = 676, (BosIDP) = 5,295, (BosRIDPDP) = 134, (TotsetBos) = 6,682, and (CBosNewIDP) = 17,179. The dynamics of the Bosnian resettlement process indicate some resettlement (Figure 41). However, many new internally-displaced individuals are created due to new disturbances of settled individuals (Figure 44).

These initial refugee resettlement models have provided an environment within which a series of studies of the impact of different refugee resettlement policies could be carried out. Model coefficient values represent the rates at which different modeled activities are assumed to take place. Selected values can represent a particular instantiation of the overall refugee resettlement process. Variation in the values of those coefficients could reflect the use of different policies or methods of resettlement and the model could be used to assess the effectiveness of such policies and methods. Of particular interest is the ability of the model to represent the impact of the disturbance of newly resettled refugees and displaced individuals (Figure 44). Davis has pointed out that his development of the refugee resettlement models upon which some of the models in this paper are based provided an early indication of the need for additional facilities and capabilities of internally-displaced individuals in Bosnia.

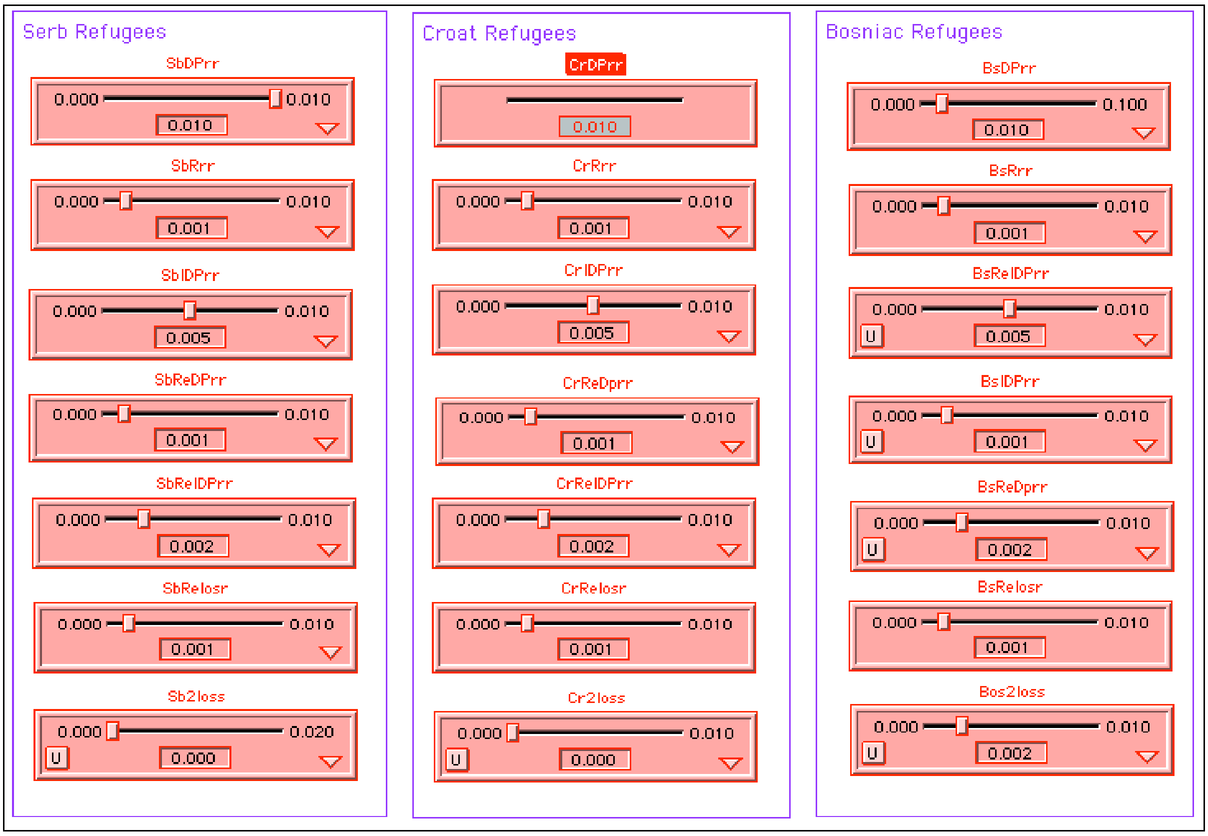

Figure 38: Selection of model coefficient values.

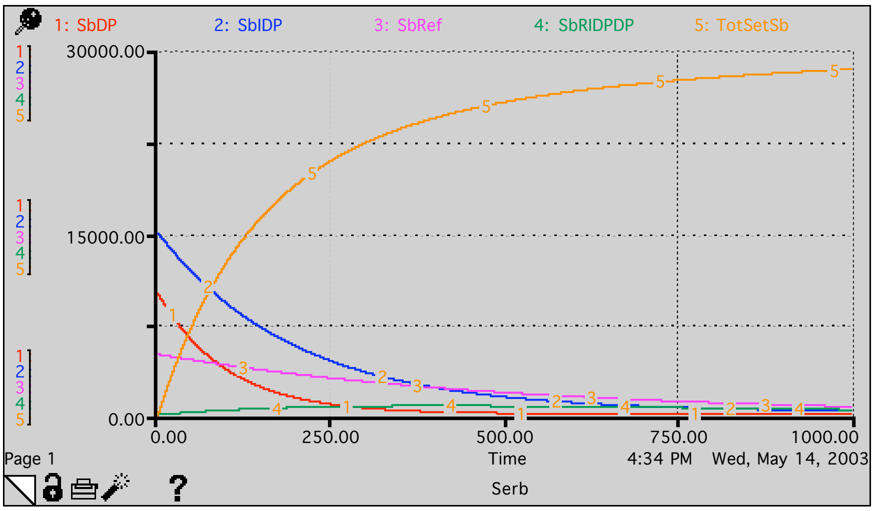

Figure 39: Calculated values for the resettlement of Serbian refugees.

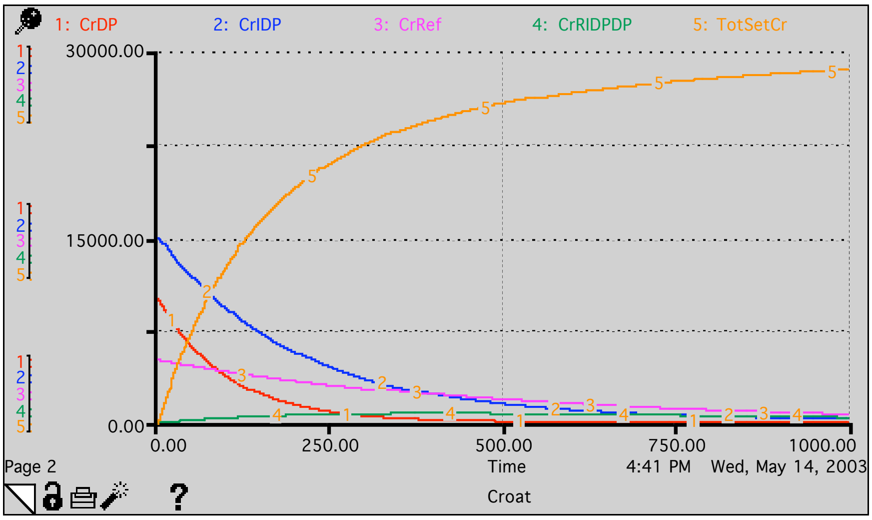

Figure 40: Calculated values for the resettlement of Croatian refugees.

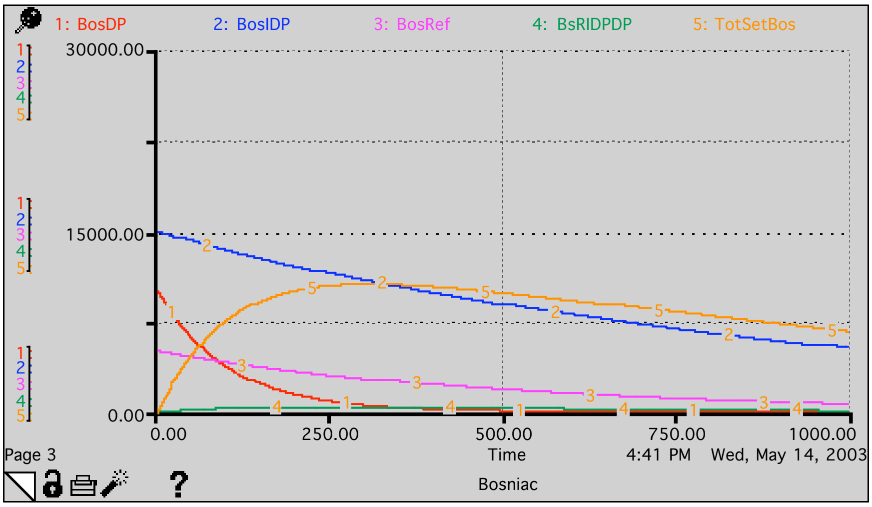

Figure 41: Calculated values for the resettlement of Bosnian refugees.

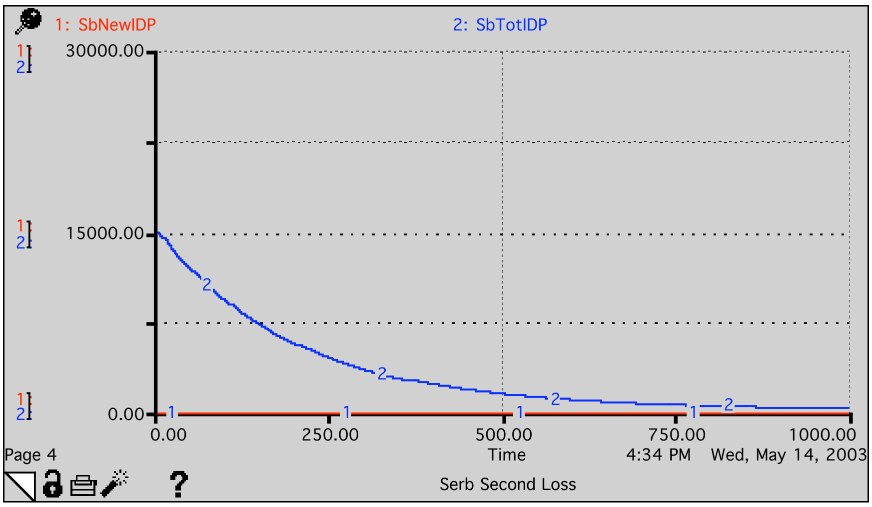

Figure 42: Calculated values for Serbian internally-displaced persons.

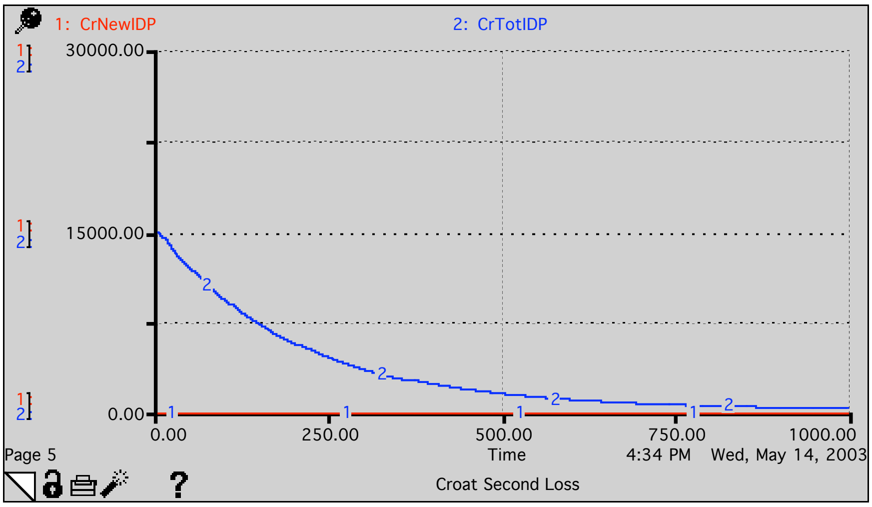

Figure 43: Calculated values for Croatian internally-displaced persons.

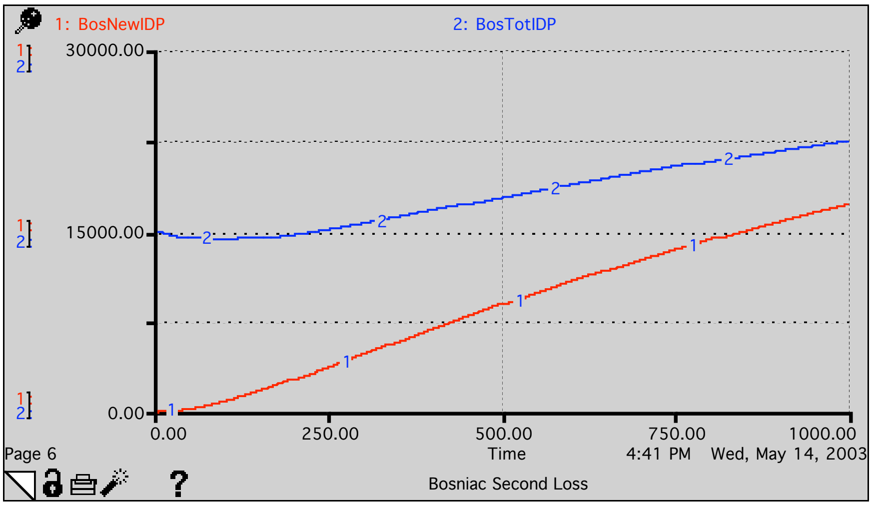

Figure 44: Calculated values for Bosnian internally-displaced persons.

SUMMARY AND DISCUSSION

This paper has described the principles of the knowledge development cycle of model building that can lead to an increase in the level of understanding of the nature and behavior of a system of interest. Initial description of a system of interest in a natural language can provide the basis for translation of that description into an appropriate mathematical language. Further translation into an appropriate computer language can provide an environment for studying the mathematical model. Results of those studies can produce new natural language descriptions, more refined mathematical models, more focussed computer models, and so on. These activities can produce an enhanced understanding of system behavior.

In order to illustrate the application of the process of model-based knowledge development, a series of time-dependent models have been developed and implemented in

STELLA™, a systems dynamics-based software system. Those models have formed the basis of the following four case studies.

1. Disaffection as a Precursor to Violent Behavior has been studied with the aid of a series of models designed to represent the processes of disaffection of individuals within a society and their expression of violent behavior. The models have been enhanced study how security forces might be deployed to reduce violence caused by disaffected individuals.

2. Disarmament, Demobilization, and Reintegration (DD&R) Processes have been modeled both as restricted and unrestricted activities. DD&R is a prelude to threat reduction, post-conflict stabilization, and reconstruction. Restricted DD&R is assumed to preclude contact of the individuals undergoing the process with combatants and ex-combatants who have not undergone those processes. Unrestricted DD&R does not prevent such access

3. Disease Models with Embedded Public Health and Medical Care Processes have been produced. These models can provide an initial basis for understanding the dynamical nature of disease processes and how public health activities can restrict or prevent the onset of disease and medical care can reduce the impact of an existing disease.

4. Resettlement Models for Refugees and Displaced Persons have been developed and used in preliminary studies of the impact of different rates of resettlement on the overall distribution of refugees and displaced and internally-displaced individuals within an overall society. Application of he models to the problem of Serb, Croat, and Bosnian refugee resettlement in Bosnia-Herzegovina have illustrated the 'Bosnian Bounce' phenomena actually observed when newly settled Bosnians were subsequently disturbed and displaced.

The models presented in this paper are intended as a form of 'work-in-progress' in developing new levels of understanding of the nature and dynamics of complex societal processes. They are intended to show what is possible and how a series of models can be constructed and used to develop an increasingly detailed understanding of the nature and dynamics of systems of interest. Suggestions have been made on how the models presented in the paper could be enhanced and modified and even integrated with other models. The process of model enhancement can identify how other modeling approaches could provide benefit to their users. One such approach used by the author and his colleagues that they have called Intelligent Automata has developed space- and time-dependent models of systems of interest.

Model-based techniques for identifying and suggesting effective responses to new and emerging challenges would be particularly important for the management of risk in the caused by terrorist and other threats. Application of models to specific tasks where actual, life-dependent, decisions have to be made must be undertaken with great care. There is a real need for *caveat emptor* for those in the model-building and model-using communities. Adequate levels of model validation and verification need to be performed under such circumstances, and it should always be borne in mind that a model, is a model, is a model …

REFERENCES

Davis, David. 2002, Personal communication.

Bailey, N.T.J., 1957. *The Mathematical Theory of Epidemics*. Griffin.

Murray, J.D., 1993. *Mathematical Biology*. New York, New York: Springer-Verlag.

Richmond, Barry, 2001. *Introduction to Systems Thinking*. Hanover, New Hampshire: High Performance Systems.

Thomas, Richard, 1992. *Geomedical Systems: Interventions and Control*. Routledge.

ACKNOWLEDGEMENT

Access to and use of a model of refugee dynamics developed by Professor David Davis, George Mason University Program on Peacekeeping Policy as well as extensive discussions with Davis on the modeling and simulation of peace operations and related areas is acknowledged with much gratitude.