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MILITARY FORCE STRUCTURE AND REALIGNMENT "SHARPENING THE EDGE" THROUGH DYNAMIC SIMULATION

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ABSTRACT

A unique approach is developed for analyzing force structures of the armed forces of the United States. With this approach new ways of measuring combat readiness are available to ensure that the armed forces remain ready to fight during the defense drawdown of the 1990s.

As part of the approach, a symbolic network representative language was developed which combines the continuous variable features of system dynamics and the discrete event features of conventional simulation techniques. This network representative language, referred to as Dynamic Simulation (DYNASIM), is built to integrate with the network SLAMSYSTEM environment.

The contribution of this research is a prescribed method for the strategic analyst to develop an influence diagram which can be used to analyze force structures within the combat logistics domain. DYNASIM's format structure enables the user to focus attention on the development of the model, rather than the computational aspects of simulation.

1 INTRODUCTION

The military is experiencing significant problems in depicting the proper force level of arms, equipment, personnel, systems, etc. In looking into each of these areas the approach is often one of production and inventory. The personnel dilemma, for example, is one of proper recruitment, life cycle or throughput analysis, and finally retirement. This is the production aspect. The personnel numbers are not simply defined under one attribute, but many thousands of attributes. How many infantry, artillery, fighter pilots, bomber pilots, submariners, medical staff, etc., are needed? This is the inventory aspect. How does the system adapt to force reductions, depletion through conflict and/or deployment? This "production" and "inventory" instability of personnel is also widespread in industry. Trying to stabilize the employment level to the demands on the organization is extremely difficult.

This variability imposes costs on the military, and the national economy. During conflict periods, the military experiences "production" inefficiencies because of personnel and equipment shortages, lack of new recruits, fatigue, and potential failure through lack of sufficiently trained personnel and lack of sufficient modern equipment. In peace time, the military experiences idle resources and excess inventory.

This paper proposes a solution to this dynamic dilemma by integrating system dynamics and combined simulation. The result is a more suitable methodology to adequately predict and control a proper balance of the total force.

2 SOLUTIONS THROUGH INTEGRATION

The objective of system dynamics, as utilized in this paper, is to study the causal relationships bearing on the combat logistics domain, and effectively identify the variables which will effect the force structure.

The application of system dynamics to problem solving entails several important features not usually found in standard open loop simulation architecture.

First, such problems are looked at as being dynamic, involving quantities which continually change over time. Next-event simulation may not accurately portray the constantly changing variables or quantities under investigation. Such quantities are expressed in terms of graphs of variables over time. The oscillating levels of various military specialties, units, equipment, etc., over a projected time period are non-linear and dynamic. Force structure reduction and realignment is a dynamic problem, continually anticipating a future threat, based on past experience, coupled with additional complications such as new equipment, changing strategies, and arms reduction. This situation is further complicated when confrontation escalates, requiring quick commitment of large forces of equipment and personnel. Typical static approaches, such as linear programming, to solving such allocation problems often cannot be used where the problem scenario changes continuously through time.

For example, it may be advantageous to model an increase in demand, (a sudden increase in troop deployment), in order to determine how quickly the soldier population returns to steady state. Or, what effect would the doubling of certain inventory of stocks have on production or soldier recruiting rates in the short term? Disrupted systems were clearly evident with the activation of the Ready Reserve Force for the invasion of Kuwait. The activation effort severely strained the resources of the Ready Reserve as well as the commercial industry in the United States (Ott 1992).

These and similar questions can only be answered efficiently with a simulation method which can cope with delays, flows of information, and material, obviously lending itself to the study of transient phenomena.

When such a simulation model is developed, the state variables are continuously changing and their time variation may depend on other state variables, both discrete and continuous. The dynamic behavior of these variables describes the real system and their computational relationship is critical to achieving reliable results.

A second feature, and the most critical, to solving force structure problems to which the system dynamics perspective applies involves the notion of feedback. Essentially, feedback is the transmission and return of information. A feedback loop is a closed sequence of causes and effects. A series of interconnected sets of feedback loops is a feedback system. Force deployment is an example of a large scale strategic feedback system. Insertion or commitment of troops, equipment, and support elements to support military strategy deplete the overall force structure inventory. As force levels fall below desired levels, a dynamic look evaluates the time and resource requirements to restock or maintain required force levels.

The delay of information feedback combined with the delay or time to produce the required assets is an area of great concern. How do we evaluate our current force structure, inclusive of the congressional mandated reductions, and provide insight as to whether or not the mission requirements can still be met? Thus, understanding of the behavior of feedback systems is a goal of the system dynamics approach.

3 MODEL DEVELOPMENT

3.1 Formulation

Figure 1 is a basic flow diagram of the physical accumulations and flows in the scenario previously described. A complete model of the system would also include the mathematical relationships describing how the accumulations and flows are calculated.

This system is characterized as a troop strength being increased by recruitment and decreased by successive maturation through the organization. This structure is unique to the military in that there are no input flows depicting recruitment from outside the organization entering into the model, except for initial recruitment. Promotions are always from within the organization, with carefully planned maturation rates between each promotion level.

The goal of this model is to accurately portray the levels of each group to aid in aligning actual force structure with congressional mandated requirements. The data used in this example are for illustrative purposes only and are not intended to represent actual numbers or current policies.

The DYNASIM representation is next described in detail. The equations and functions used in this paper are presented. A complete description of all DYNASIM equation types, functions, including n^{th}- order delays, can be found in Parker (1994).

The ALPHA node symbol represents the initialization or entry points into the simulation. The OMEGA node symbol represents termination to outside the system. The CLOCK represents initialization; time parameters, increments for DTNOW, stop time, etc. The GRAPH node depicts the variables which the EXCEL macro will transfer the data for simultaneous representation of the variables.

The levels are shown, representative of the SLAM II state variables. These levels are simplistic in this scenario, representative of the initial conditions in building a much larger simulation model representing a very large population of military personnel. The three dimensional representation mimics the potential growth of a much greater modeling initiative.

Arrows in dark black represent flow rates. Because of the limited detail in this figure, the rates do not depict the variables and numerical values. Arrows in light gray color depict information links, (causal representation). These arrows are not necessary in the DYNASIM representation. However, they are shown to aid in understanding the relationships.

Next, consider analyzing the equation types for the DYNASIM flow diagram in Figure 1. A brief description is given, along with the equation format.

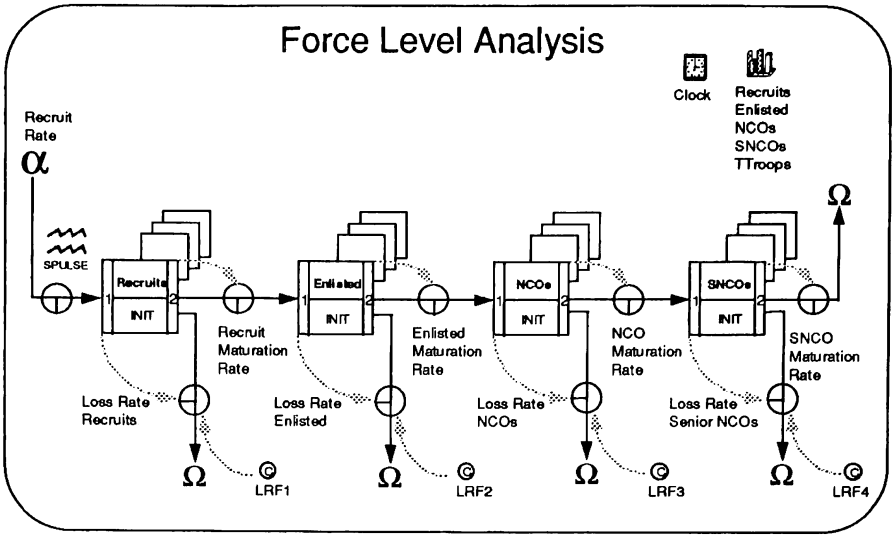
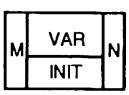


Figure 1: Network Soldier Maturation Model

3.1.1 Levels

Symbol:



Format: LEVEL(VAR), INIT, M, N.
Function:

The levels represent the values of the variables under study through time.

The level symbol is shown above as a rectangle. The center denotes the variable name, 'VAR'. 'VAR' represents the variable name to investigate. The 'M' represents the number of incoming rates or equations, and similarly the 'N' represents the number of outgoing rates or equations. 'M' and 'N' must be greater than or equal to one. 'INIT' represents the initial number of units or items to initialize the variable level or state.

The equation represented by the symbol is:

$$x_{i,t} = x_{i,t-1} + DTNOW \times \left(\sum_{j=1}^{M} rate.in_{ji,t-1} - \sum_{k=1}^{N} rate.out_{ik,t-1} \right) \quad (1)$$

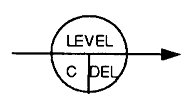
where

$x_{i,t}$ = state variable level i at time t
$x_{i,t-1}$ = state variable level i at time $t-1$
$DTNOW$ = delta time interval in SLAM II
$rate.in_{ji,t-1}$ = flow rate j into level i at time $t-1$, $j=1,\ldots,M$
$rate.out_{ik,t-1}$ = flow rate k out of level i at time $t-1$. $k=1,\ldots,N$.

Levels are calculated at each of the closely spaced SLAM solution intervals, DTNOW. The equation for the Level symbol states that $x_{i,t}$, the present value of x_i at time t (TNOW), is equal to the previously computed value $x_{i,t-1}$ (TTLAS), plus the difference between the inflow rate, *rate.in,* during the last time interval and the outflow rate, *rate.out,* the difference in rates multiplied by the length of time DTNOW during which the rates persisted.

3.1.2 Rates

Symbol:



Format: RATE (LBL), LEVEL, DELAY, C.
Function:

The rate symbol is used to depict the rate of flow. The rate equations are of great importance in that the changes to all the levels in the model are attributed to some form of the rate equation. The rate equations associated with this symbol are usually found either entering or leaving a level node. The flow rate may be a function of several variables.

Flows into a level node are positive (+) and flows out of a level node are negative (-). 'LBL' denotes the label name. 'LEVEL' depicts the variable which the rate affects. 'C' is the constant representation. 'DEL' represents the delay or average time the contents of the level will traverse the rate equation.

The first rate equation format presented is:

$$rate \quad = C \times level \qquad (2)$$

where

$rate$ = flow rate in or out of the level (units / time)
C = constant (fraction / time)
$level$ = present amount of variable (units).

This format is typical of the formulation in simple models involving growth, shrinkage, or whenever the assumption of a constant fractional growth rate could be justified. 'C' represents a system constant multiplied by the existing level. A simple modification to this equation format is the replacement of the constant with a variable.

The second rate equation format presented is:

$$rate \quad = level \,/\, delay. \qquad (3)$$

This equation is similar to equation (2) differing only in that a delay is added as a constant, depicting the average length of time to traverse a delay. This format is supportive of depicting the in or out flow in relation to a level. The delay can be thought of as the average lifetime or the average time of that a unit remains in the level before it flows on.

The level in an equation can also be modified to model the desired level against the actual level. This formulation is a general structure striving to bring the actual state of a system closer to some desired goal. Normally depicted as a negative loop structure, the level depicts the desired (goal) minus the actual level. The constant delay represents the adjustment time, or a period over which the rate tries to close the gap between the level and its goal.

Thus, combining the descriptions of equations (2), and (3) above, the following rate equation format is provided

$$rate \quad = C \times level \,/\, delay. \qquad (4)$$

3.1.3 SPULSE Function

Symbol:

Format: SPULSE(AMNT, FTIME, INTVL, NINT).
Function:

The SPULSE is a time function used to model momentary jolts or pulses in a model representing isolated changes in a variable, returning it immediately to zero after each change. 'AMNT' represents the height of the pulse. 'FTIME' represents the time of the first pulse. 'INTVL' represents the time interval between successive pulses. 'NINT' represents the number of intervals desired. The equation

INCRMT = SPULSE (3000, 2040, 1, 200) (5)

represents a variable name INCRMT equal to 3,000 beginning at time 2,040, reproduced every 1 year for 200 iterations.

3.1.4 Auxiliary Equations

Symbol:

Format: VAR = AUX.
Function:

Auxiliary equations are similar to rate equations in that they are evaluated at each SLAM DTNOW increment. Auxiliaries can be substituted into a rate equation of which they may form a part. Thus, auxiliaries are located in subroutine STATE.

Auxiliary equations usually are depicted as the pieces which make up the larger rate equations, broken into smaller sets to enable the modeling task to be more simplistic. Therefore, the format for the auxiliary equation is rather simple, allowing the analyst to formulate any expression which is mathematically feasible. For example,

TROOPS = ENLISTED + OFFICERS (6)

represents the variable TROOPS, as the sum of the ENLISTED and OFFICERS, calculated at each DTNOW increment.

3.1.5 SCLIP Function

Symbol:

Format: SCLIP(DA, DB, VX, VY).
Function:

The SCLIP is a logical function which enables the analyst to change the values of variables during a simulation by providing a conditional choice between two values. For example, the equation

INCRMT = SCLIP (0, 1000, LEVEL, 14000) (7)

states that the variable name INCRMT is equal to 0.0 if variable LEVEL is greater than 14,000 and INCRMT is equal to 1,000 if LEVEL is less than or equal to 14,000.

3.1.6 SSTEP Function

Symbol:

↱

Format: SSTEP(HGT, STIME).
Function:

The SSTEP is a time function used to change a quantity instantaneously at some point in time. 'HGT' represents the step height, 'STIME' represents the time at which the step is to occur. For example, the equation

$$\text{TROOPS} = \text{SSTEP}\,(14000, 2040) \tag{8}$$

represents the variable name TROOPS will assume a value of 14,000 at time TNOW greater than 2,040.

4 ANALYSIS

4.1 Base Case

Many simulations were run to acquire an equilibrium position satisfying all initial constraints (Parker 1994).

Figure 2 represents one objective of the analysis in predicting the time span necessary to reduce the total force structure from 110,000 to 60,000. Enlisted, NCOs, and Senior NCOs, reduce proportionally. All other factors and units remain the same.

The process was to manipulate only the input parameters, recruit rate (RRATE), to ensure drawdown by least cost.

Notice that at time 2,040 the drawdown of 6,000 troops per year is initiated. The final plateau is reached at approximately year 2,070. Thus, the gradual drawdown at the lowest cost risk through this rate of reduction may take approximately 30 years.

4.2 Second Analysis

This scenario was similar to the previous scenario in that the initial conditions remained the same.

The objective of this scenario is to adequately predict the time span necessary to recover the total force structure after a one time reduction of 14,000 troops for each level equation, excluding the recruits. This scenario is important in understanding the recuperation times necessary after deployment of forces, or losses unrecoverable. Unlike the previous example, the reduction will be conducted once

The results of this analysis can be seen in Figure 3. Notice that at time 2,040 the drawdown of 14,000 troops per year for one year is initiated for each level. The final plateau or recovery period is reached at approximately year 2,066.

Thus, the sudden drawdown of 14,000 troops per level may take approximately 26 years to stabilize. This assumes the total maturation of each level remains "as is". The rate of return of the force level is inadequate and must be compensated in a more expeditious manner.

4.3 Enhanced Feedback Loops

The previous model runs provided insight into modeling force structures with emphasis on determining the inputs and outputs based on a search strategy or "ceteris paribus" approach. In this section the emphasis is on modeling the same situation with a more "closed loop" architecture. The result is a self-regulating system. Figure 4 shows the original scenario with the addition of several auxiliary feedback loops. Notice that the model now generates a recruit rate (RRATE) from the troop levels; Enlisted, NCOs, and Senior NCOs. The objective, or goal, is to compensate for a state variable loss by increasing the flow rate until the desired level or goal is desired. As a level decreases, the recruit needs to increase. This "negative" feedback structure is developed in this scenario.

The "closed loop" architecture previously described, depicts the input recruit rate (RRATE) as the result of summing all the auxiliary equations which provide input into the system. Therefore

$$\text{RRATE} = \sum_{i=2}^{4} \text{RR}_i \tag{9}$$

where i = 2 for Enlisted, 3 for NCOs, and 4 for SNCOs.

Thus the original RRATE equation has been changed to reflect the summation of the three auxiliary equations RR2, RR3, and RR4.

A disturbance is introduced into the system in the form of a drawdown or sudden reduction in troop levels. The objective of this scenario is to display the recruit rate as a function of the accumulations, and introduce instability by the elimination of troop strength. This scenario is an excellent example to incorporate the use of the DYNASIM SSTEP function and the SCLIP function.

In the test scenario, the levels or accumulations of the troop strengths are reduced at time (TNOW) equal 2,040. The current Enlisted number will decrease by 8,000 soldiers. Similarly the NCOs will decrease by 6,000, and the Senior NCOs by 4,000 personnel respectively. This is accomplished through the use of

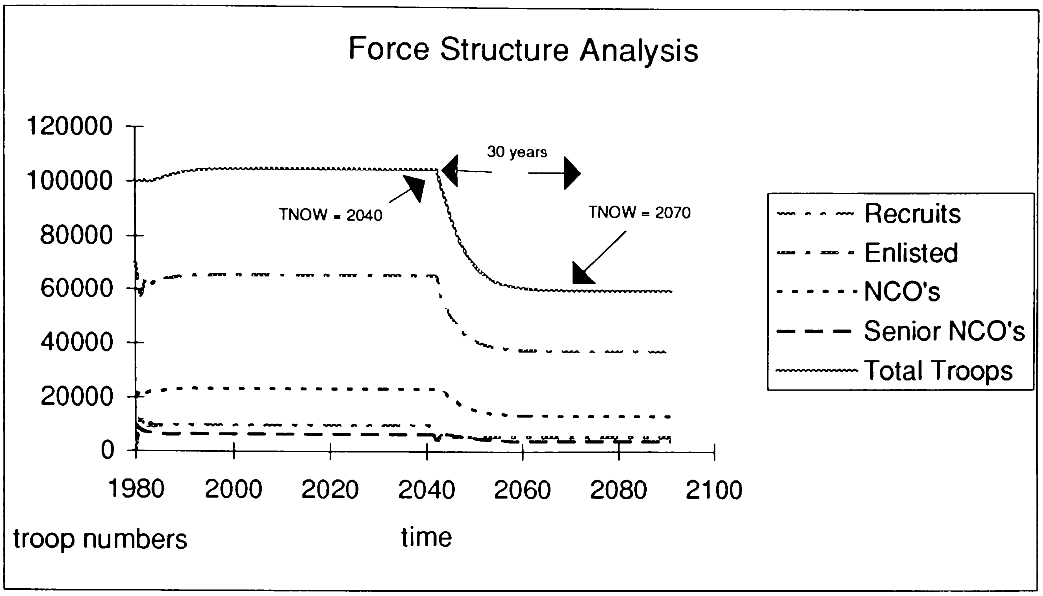


Figure 2: Least Cost Force Level Drawdown

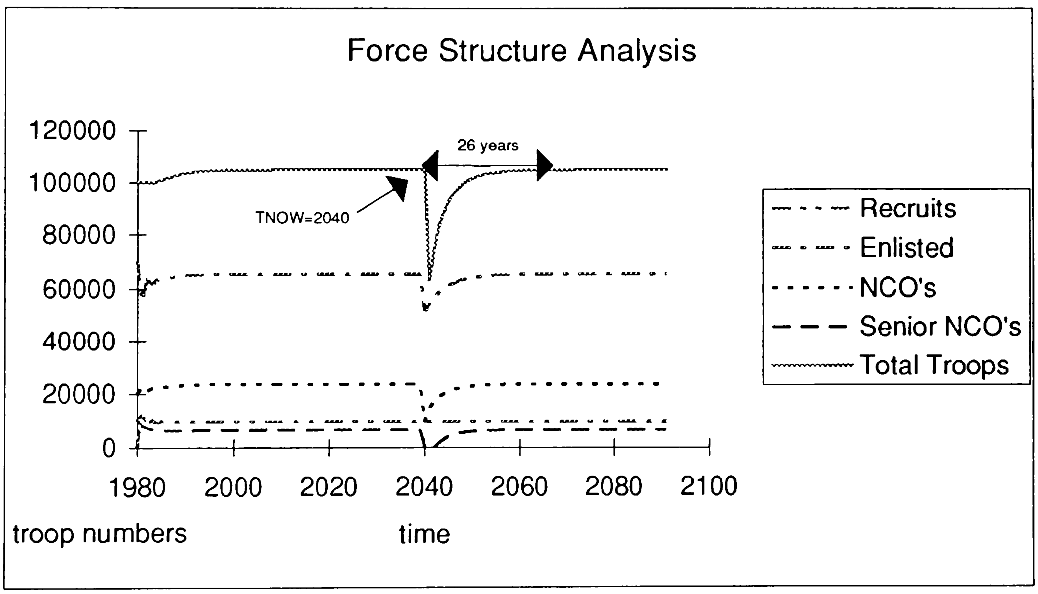


Figure 3: Least Cost Force Level Recovery.

three SSTEP functions. Because of the sudden reduction in the total force, a "self-actuating" or correcting mechanism must be employed.

This compensation is accomplished through incremental additions to RRATE. The original recruit rate equation (RRATE) is rewritten with the addition of an auxiliary in the form of a SCLIP function. Thus, the RRATE equation is now written as

$$RRATE = \sum_{i=2}^{4} RR_i + INCRMT \tag{10}$$

where INCRMT represents the incremental change.

INCRMT is in the form of the DYNASIM function SCLIP.
The format is depicted as

$$INCRMT = SCLIP\ (0,\ 1000,\ RRATE,\ 14000) \tag{11}$$

where SCLIP describes the function as follows:

$$\begin{aligned} INCRMT &= 0.0 && \text{if } RRATE \geq 14{,}000 \text{ and} \\ INCRMT &= 1000.0 && \text{if } RRATE < 14{,}000. \end{aligned}$$

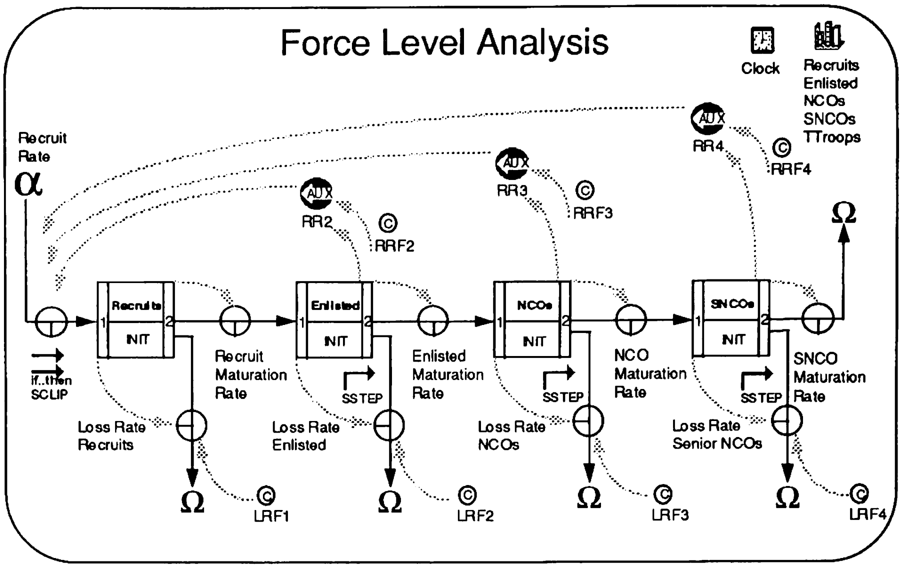


Figure 4: Network Model With Enhanced Feedback Loop

This incremental procedure will essentially continue to increase the recruit rate in the positive direction until the RRATE is equal to 14,000, stabilizing the system as previously desired. Figure 5 depicts this scenario and results. Notice that it takes approximately 20 years to recover from the original loss of 18,000 total ((-8,000) + (-6,000) + (-4,000)); a more stable recovery than in the earlier example.

5 SUMMARY

There are two major contributions which stem from this research. First, an alternative method of analyzing force structure is presented. Current methods fail to include mission strategies, depicting the use of United States assets in various roles and configurations. Depletion, and delays attributed to reconstitution and reconstruction are hidden but highly important considerations in evaluating force strength.
With a smaller force the Nation is depending on a rapid and timely activation of reserve and ready reserve forces.

Integration with industry is a critical variable with which needs great consideration. Industry is a strong but complicated asset which needs to "fit" into the strategy for force development. To schedule construction of carriers, nuclear attack submarines, fighter aircraft, etc., requires a great deal of understanding of the system dynamics involved in projection of future force structures, such as that predicted for "Force XXI". Mission policy should guide the force structure. The dynamics of the force structure should be then analyzed to ensure the appropriate strategy and tactics to support such policies.

The second contribution, the addition of the symbolic nodes and functions representative of the system dynamics and the domain study enhance the current capabilities of the simulation platform SLAMSYSTEM. This combined modeling structure increases the flexibility of the simulation platform to perform dynamic force structure analysis. Such combined modeling structures increases the capabilities of performing simulation analysis, particularly where continuous variables require greater understanding.

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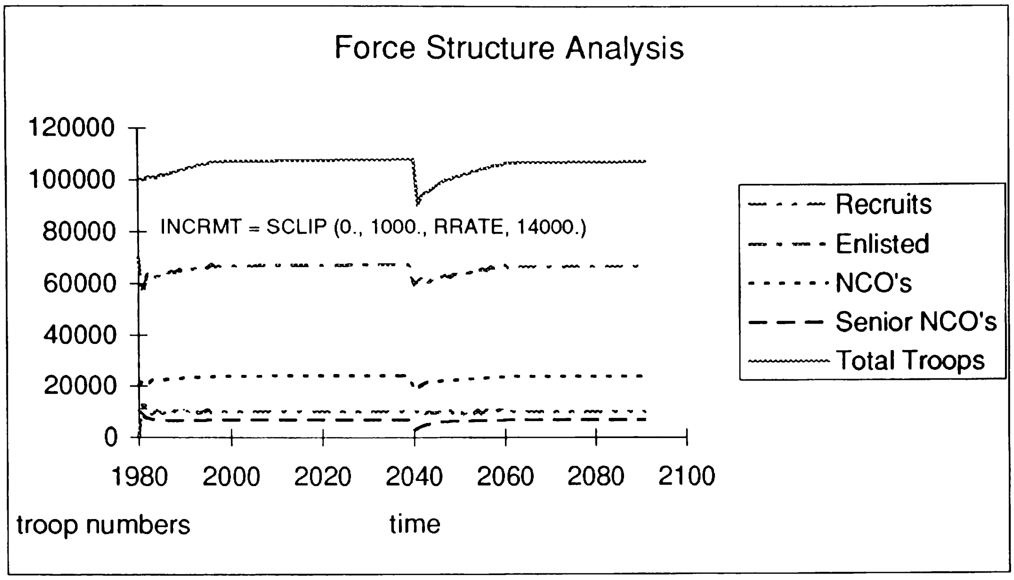

Figure 5: Force Structure Analysis with Self-correcting Factor

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