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# The Inventory Asset Analyzer:
## A Tool for Reasoning about Force Modernization Planning

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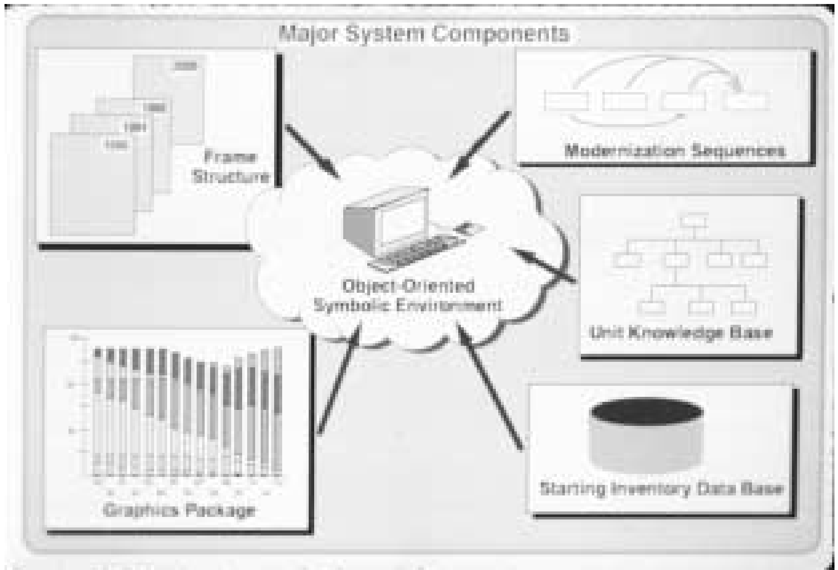
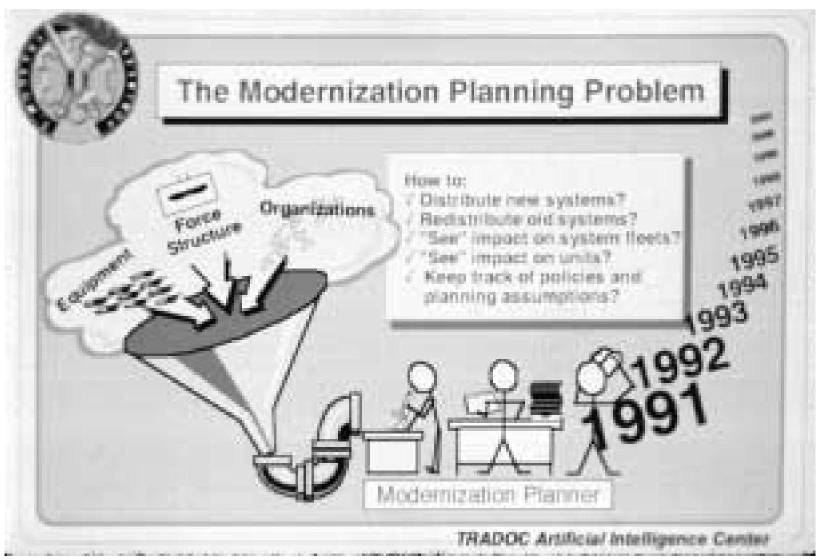
Defense planners spend considerable time generating and evaluating options for modernizing our nation's aging fleets of weapon systems. In the U.S. Army, this process involves generating plans for modernizing units with new equipment and identifying efficient strategies for using older equipment. Dynamic constraints and variables such as changes in defense doctrine or military force structure can affect these plans. Other constraints are administrative or political in nature, such as retirement policies or budgeted procurement quantities. Key parameters can change daily, and the decision maker rarely has the ability or time to specify what kind of solution is optimal or most desirable. Selecting an appropriate modernization formula is largely an iterative process of evaluating the trade-offs between real-life resource constraints and the effect on the organizations that own the systems.

The Army's Training and Doctrine Command (TRADOC) automated the fleet-modernization and resource-distribution planning process by developing a series of object-oriented models that simulate the fleet-


Major System Components
Frame Structure
Modernization Sequences
Object-Oriented Symbolic Environment
Unit Knowledge Base
Graphics Package
Starting Inventory Data Base


The Modernization Planning Problem
Force Structure
Organizations
Equipment
How to:
✓ Distribute new systems?
✓ Redistribute old systems?
✓ "See" impact on system fleets?
✓ "See" impact on units?
✓ Keep track of policies and planning assumptions?
1997
1996
1995
1994
1993
1992
1991
Modernization Planner
TRADOC Artificial Intelligence Center

modernization process. Using a Lisp machine environment and rapid prototyping programming techniques, we built a deterministic framework to model and project the long-range implications of fleet-modernization decisions. By incorporating an interactive graphic user interface, we are able to support the iterative process of generating modernization plans by tracking all important decision variables and allowing the user to graphically see the effect that a plan will have on the organizations and fleets being modernized. We present how this methodology was successfully applied to two problem domains: aviation and armor modernization planning.

## Nature of the Planning Problem

*Modernization planning* is a dynamic and complex process. Planners are constantly evaluating and adjusting the way that the Army's fighting units are organized to meet changing world events. In times of fiscal restraint, such as the Army is currently experiencing, new equipment plans can be modified, delayed, or canceled. Likewise, some units might have to be eliminated, moved, or even reduced in size.

New equipment is usually procured over a number of years, and some units will have a shortfall in modern equipment with respect to mission needs as the new equipment is fielded. This issue can represent a risk that the planner must track and make visible to the decision maker so that priorities can be established. Other planning requirements might call for a reorganization or reduction in units and the redistribution of excess resources.

In most cases, the modernization planner's overall goal is to devise a strategy for distributing whatever new resources are available to units with the greatest priority while redistributing the displaced resources to lower-priority units that can use the older equipment. To effectively do this planning, the modernization planner must be familiar with a wide variety of issues, such as current and new system characteristics, equipment rebuilding or refurbishment programs, unit modernization options, and organizational relationships. At a high level, this process simply involves the distribution of new systems and the redistribution of older systems between Army units. At a lower level, planners are often asked detailed questions about the implications that equipment modernization plans can have on the individual units, organizations, and equipment fleets.

The planning process is complicated because few factors are static throughout the typical 15- to 25-year planning horizon. For example, doctrinal changes to unit missions, structure, equipment requirements, weapon system characteristics, or budget fluctuations can affect the availability of new resources. Other issues include modernization dependencies between different systems of equipment or policy and strategy constraints for redistributing the old resources.

Changing any one of these parameters can result in an entirely new modernization planning schedule, often with undesirable side effects on unit turbulence or system incompatibilities. The dynamic and flexible nature of this process thwarts attempts to obtain a goal consensus, and a resulting modernization plan is rarely an optimal solution with respect to all key constraints.

## Modernization Planning with Army Aviation

TRADOC was formed in 1973 to prepare the Army for war through the development of doctrine, weapon systems, equipment, organization, and training. Doctrine determines how Army units should fight and be supported through standardized tactics, techniques, and procedures. Along with doctrine development, TRADOC supervises a process known as combat development, which details how we should organize and equip our units so that they can fight according to doctrine.

In December 1987, TRADOC conducted a combat development study to determine what options were available for maintaining and modernizing the Army's fleet of aging rotary wing aircraft. Most of the fleet had been placed in service in a relatively short period of time (mid-1960s to early 1970s), and commanders were unsure about how the mandatory retirement of older aircraft would affect the Army's aviation forces over the next 20 years.

Several modernization planning options were developed as the problem was studied. Each of these options was laboriously produced (over 100 person-hours for each option) and based on the following: (1) static macro inventory projections involving 9000 aircraft in 500 aviation units at fixed points in time, without transitory details about how individual units changed over time; (2) aviation functional experience, expertise, and judgment about possible and desirable *modernization transition paths* for the various types of units (a modernization transition path can be thought of as a logical sequence of organizational structures that are progressively improved combinations of aircraft models and types); and (3) many complex and undocumented analysis assumptions.

Human judgment was vital in conducting an analysis because of the diverse number of different modernization paths that units could take and the many exceptions to the typical paths for a certain unit. Although many units are fundamentally similar in mission, other factors such as geographic location or proximity to supported units created exceptions in the way the units were modernized and prevented the planners from using traditional numeric representations to do automated inventory projections. Thus, modernization analysis was usually performed manually by a group of functional experts and recorded on a simple spreadsheet for historical purposes.

Many simplifying assumptions were also necessary to produce an analysis within a reasonable amount of time. For example, when preparing a modernization plan, the analysts decided to exclude units that own aircraft but had no combat missions, such as units with training missions. This choice was necessary because there was no convenient way to compute what the units really needed to modernize because these types of unit organizations were so varied and different. Results based on this kind of premise can be misleading because units in this category own nearly 20 percent of the total inventory. Assumptions such as these were seldom documented because they were considered common knowledge by the functional analysts but became critical when trying to justify an answer.

As the study progressed, and issues became more complex, the TRADOC Artificial Intelligence Center was asked to build a decision support tool that allowed an iterative what-if modernization analysis. The Artificial Intelligence Center had recently been created to apply AI and other advanced software technologies to solve complex analytic problems, and this project was our first major one.

We began our work by observing several planning sessions and identified that the analyst needed an automated way to generate a modernization plan from a given set of assumptions while he/she portrayed the composite status of an entire aircraft fleet at any point in the planning period. Decision makers often asked the functional experts how the composite fleet status affected certain individual units; so, we decided that our system would also have to be able to provide the status of any individual command or unit to be useful (even though the actual identity of the unit in question probably wouldn't be known until after the analysis was completed).

To be accepted, the system needed to be interactive and easy to use and to lower the analyst's cognitive requirements by tracking detailed assumptions. We intended for our system to be used in the development, analysis, and presentation of alternative modernization plans as well as a historical reference for past plans and key assumption parameters.

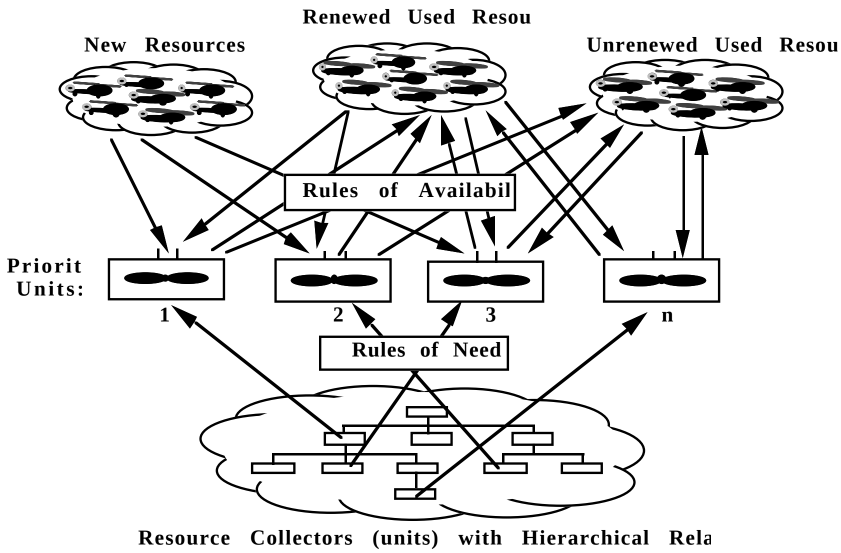



*Figure 1. Conceptual Overview.*

## Development Methodology

We quickly discovered that the functional analysts were not interested in building an abstract model that produced only statistical or numeric results because such models had already been built; in addition, no one understood the system malfunction when it issued some unexpected output. Our task was to provide a user-oriented tool that automated the approach the analysts were using in their manual analysis. This development strategy allowed us to perform knowledge acquisition and also provide incrementally increasing support as the functional experts continued to work on the problem. By using a rapid prototyping approach, we also became more knowledgeable about the nature of the problem and were able to incrementally define an object-oriented solution to this problem.

## System Description and Components

To discuss our system, it is first necessary to describe the major components of the problem. At the highest level, the modernization problem is a matter of distributing scarce resources (aircraft) into resource collectors (units) over time. Units can have hierarchical parent-subordinate relationships and can change relationships over time as units activate, become inactive, or are moved. Unit hierarchical relationships also have the ability to change with different mission contexts.

Resources are classified as *new* (from the production line), *renewed* (used and reconditioned), or *unrenewed* (used and not reconditioned). *Rules of availability* were used to describe where these different types of resources could be distributed, such as restrictions by theater of operation, and how long they could be used by resource collectors before being retired.

Resource collectors compete for these resources based on *rules of need* that vary based on the types of resources available. Success in competition between resource collectors is based on factors such as individual or parent unit priorities and other global constraints (figure 1). Equipment template families are created to reflect the possible model, series, and quantity of equipment combinations that a unit could expect to have during a planning analysis. Modernization paths within template families are hierarchically organized and prioritized based on desirability. Pattern matching with available equipment (determined by rules of availability) is used to select a specific modernization path for a unit that is attempting to modernize.

We use a frame-based data structure to store the starting state of each unit and inventory asset, key assumption parameters, and analysis results for each year in a planning analysis. Rules and constraints are highly visible and easily changed through pop-up menus to reduce the system complexity. The visible encapsulation of functional aviation expertise into rules allows the system to be used in multiple locations, where different options can be developed and analyzed. Wherever possible, rules handle the full range of expected values and have the ability to be turned off when deemed appropriate.

Using the object-oriented symbolic Lisp Machine environment and the rapid prototyping development technique, we incrementally built our system by defining and adding new behaviors to unit and aircraft objects. This approach enabled us to provide the user with a working model to critique and use to describe additional needed behaviors or modifications without having to specify all the system requirements up front. The functional expert had a working system within 30 days, and we continued incremental development for 6 months without needing any major code revisions.

Because of the modularity of object-oriented code, we were able to proceed with the development of an analysis engine while a key portion of the user interface was developed at the Department of the Army Artificial Intelligence Center located at the Pentagon. This graphic interface module, called the business graphics package, was developed in parallel with our efforts through minimal coordination and high-level behavior specifications. This development paradigm

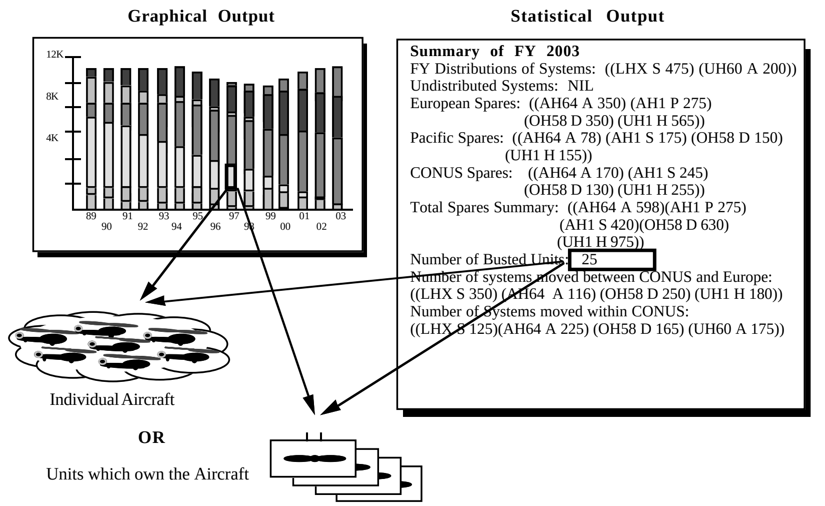



*Figure 2. Linking Output Back to Data Objects.*

also offered extensive leverage in the form of a high-level implementation that was readily exportable into other domains.

## Performing an Analysis and Reviewing Results

When performing an analysis, the user first reviews and changes appropriate system rules and parameters, then selects the start and end years of the analysis. Vital statistics for each year are displayed on the screen, such as the number of new aircraft distributed, the number of spares remaining in each theater, the number of aircraft moved between theaters, or other critical information that the analyst desires to monitor. A 20-year aviation modernization analysis requires approximately 22 minutes and is able to track the status of individual units and aircraft throughout the entire analysis period. This performance compares with a typical 120 person-hour manual analysis—an improvement over 300:1 in analysis time alone.

On completion of an analysis, the results can be reviewed year by year in the form of bar, stacked bar, or line graphs. Macro-level views of aircraft by fleet totals, location, or average ages are available through a series of pop-up menus. The graphic decomposition of aircraft or unit totals into any of the hierarchical organizations or categories of units

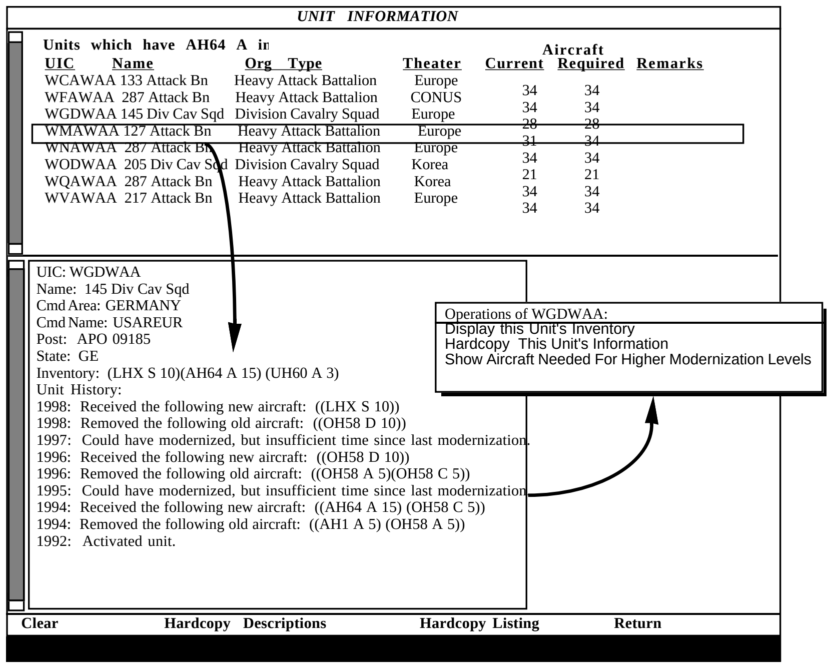



*Figure 3. Example of Information about Unit Objects and Other Available Options.*

by mission type or location is also possible.

Our involvement with the functional analyst provided considerable insight into the kinds of queries that the system would have to answer. We observed that the analyst is frequently faced with questions such as "I know I don't have enough modern attack helicopters to distribute to everyone who needs them, but are there any European units that still need them in 1995?" or "I see that there are still some outdated utility aircraft in the total fleet composition graphs in 1994—who has them?"

Our system is designed to quickly and easily answer questions such as these. By merely pointing and clicking the mouse on the statistic (a number printed to the screen) or graph element of interest, the actual units or aircraft that are represented in the statistic or graph are displayed along with a complete audit trail of everything that happened to the unit or aircraft to this point in time (figure 2). This capability is implemented using Presentation Type features that are available in the Symbolics Genera software environment.

When unit information is displayed, the analyst has the option of looking at individual aircraft that are in the unit inventory at this point in time along with an audit trail of everything that happened to the unit (figure 3). This capability allowed us to validate model behavior throughout the development process and give the user considerably more insight into the behavior of the overall system. It was also useful in showing decision makers the affects that policies, represented as system rules, can have on organizations and fleets over time.

Because our model is able to quickly return analysis results, the user is able to do many more what-if analyses, generate more robust modernization plans, and view the implications of modernization rules and policies. This ability allows the planner to incrementally navigate the solution space of possible modernization plans by iteratively generating a plan, reviewing results, changing the underlying rules, running the model again, and then examining the effects of these changes at various levels of detail. Several analysis plans can quickly be generated using different rule sets for entire analyses, or the system can be run with different sets of rules taking effect at specified times in the analysis.

New modernization plans can also be generated by blending parts of rule sets that have been used in other modernization analyses. The model tracks which assumptions have been loaded or changed and performs consistency checking on interdependent parameters. The analyst can thus focus on high-level goals, such as determining which solutions are better than others, and the system tracks what it took to get there and the differences in outcomes. The system makes the user aware of any rules that were modified and allows the user to save and reload any set or subset of rules that were used in an analysis. Likewise, any graphs or printouts of inventory or unit activity which can be displayed can also be saved or printed.

## Current Status and Other Domains

The aviation asset analyzer has been continuously expanded to deal with new modernization issues since the first prototype was delivered in March 1988. The model was first used by TRADOC combat developments staff members to document staff planning assumptions and validate the aviation modernization plan that was manually developed by the Army Aviation Center at Fort Rucker, Alabama. The model is fielded for use at TRADOC headquarters and the Army Aviation Center and is also available for analysis and review at the Office of the Deputy Chief of Staff for Operations (ODCSOPS) in the Pentagon and the Concepts Analysis Agency in Bethesda, Maryland. The model was also recently extended at TRADOC headquarters to study logistical, maintenance, and ammunition life-cycle costs as well as unit-level combat effectiveness in a cost and operational effectiveness analysis of future aircraft modernization plans.

In the fall of 1988, the aviation modernization model was converted to deal with the Army's armor fleet so that it could be used to develop a long-range armor and antiarmor modernization plan. Within three weeks, the code was converted, a new hierarchical unit knowledge base was built, and the first armor asset analyzer was delivered. Because the issue of mandatory equipment retirements was not a factor in the armor community, we were able to eliminate the burden of tracking each inventory asset and significantly improved the model run time from 22 minutes to 2.5 minutes. As we found with the aviation modernization planning process, user productivity was significantly improved from a manual 3 person-day effort by a ratio over 450:1, and much more detailed and robust modernization plans were generated.

The model was continuously used and refined over the next 8 months as new modernization planning options were generated by a special modernization task force that was formed to study the problem. At times, the task force generated as many as 40 different options in a single day. Results from the model were incorporated in the armor modernization plan and briefed to the Army chief of staff in June 1989. The model is currently used to hold all planning assumptions and results and is available for use by staff members at ODCSOPS. Because of the extensive use of Symbolics Presentation Type and Flavors, the models currently run at all locations on Symbolics 36XX Lisp Machines or embedded Ivory Coprocessor Boards.

## Summary

Our family of inventory asset analyzers represents a new, intelligent, and powerful way to develop modernization plans for the Army's fleets of costly systems. The modernization analyst is able to focus on issues and policies and view the modernization implications from a multitude of different views with various levels of detail. The system provides easy and direct access to unit or individual inventory asset histories through multiple graphic and statistical output. Through these mechanisms, the user is able to view analysis results, validate model behaviors, and identify additional changes which are needed.

The power, flexibility, and leverage of using an object-oriented Lisp environment supported the rapid prototyping of solutions that could iteratively be refined. We were able to quickly implement improvements to function as additional behaviors or behavior modifications rather than as major source code revisions. This object-oriented environment supports the easy port of our code across domains and enables us to now make functional modernization planning improvements in the armor and aviation communities as well as other domains that deal with similar modernization planning issues.

## Acknowledgments

As is the case with most significant applications, a cast of individuals contributed to the success of this model. We are most grateful to Maj. Pat Lynch at the Department of the Army Artificial Intelligence Center for his development and support of the business graphics package. Maj. Steven Mauro served as the aviation functional expert and has been succeeded by Maj. Robert Kilmer. Lt. Col. Raymond Livingston served as the armor modernization proponent while on the Armor/Anti-Armor Special Task Force, and Capt. Larry J. Harrison picked up support of the aviation asset analyzer during development of the armor asset analyzer.