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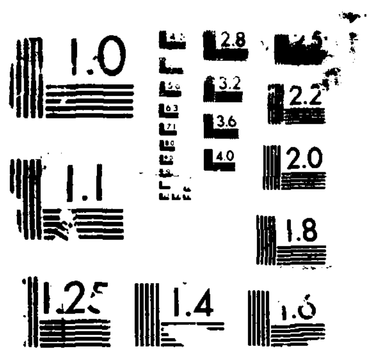

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ACAR, A DECISION SUPPORT SYSTEM TO OPTIMIZE THE ALLOCATION OF COMBAT AND AIRLIFT RESOURCES

THESIS

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Captain, USAF

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THESIS

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Masters of Science in Operations Research

Stephen L. Hager

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Preface

The initial idea of this study was to improve the mathematical programing model that had been developed by Capt James Cooke and modified by Capt David Tate and Maj Raymond Haile. As the proposal developed I decided that improving and packaging the model in a Decision Support System (DSS) would be the best method. I want to thank my faculty advisor Lt Col William Rowell and my DSS instructor Lt Col John (Skip) Valusek for their direction and assistance in creating this DSS.

I would like thank Maj Joseph Litko, my thesis reader, for his help and assistance with the formulation of the model.

I appreciate the effort of both Lt Col Rowell and Maj Litko for the many hours they spent proofing this document and making valuable suggestions for this thesis.

I would like to thank the analysts at the Hq Mac Analysis Group for their help and assistance, especially Maj Mark Donneley, Maj William Ewing, Capt Steve Knot, and Capt Mark Fowler.

Lastly, but perhaps most importantly, I would like to thank my family. I thank my wife Peggy for her love, devotion, and understanding through this trying time. And, I thank my three sons Stevie, Andy, and Mikey whose occasional interuptions help bring me back to earth and put a little joy in my life at AFIT.

Stephen L. Hager

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Abstract

The primary objective of this research is to improve and package a previously developed mathematical programing model to increase its likelihood of acceptance. The model departs from the normal measure of effectiveness of airlift, measuring ton miles per day, and allocates combat and airlift resources to maximize combat power delivered to the objective area (thus the name ACAR). The package selected to build around this model was that of a Decision Support System (DSS).

This thesis has produced a working prototype DSS that can assist Air Force and Army Planners. The primary method of design for this DSS was adaptive design. This thesis presents one complete cycle of that approach. The concept mapping technique was used to identify two kernel problems for this DSS to study. The three components of this DSS, the data base, the model base, and the man machine interface, are described in detail.

The data base component consists of the various screen displays which contain tabular data. The tables group similar items together and contain the input required to the model base component. The heart of this DSS is the model base which has been adapted from previous thesis efforts. Lotus 123 was used as a DSS generator and to generate the input for the linear programing software called XA. This DSS is a user friendly analytical tool.

(Theses)

ACAR, A DECISION SUPPORT SYSTEM TO OPTIMIZE THE ALLOCATION OF COMBAT AND AIRLIFT RESOURCES

I. Introduction

> ...when the U.S. applies force, it must be able to apply it expeditiously. Hence, high priority should be given to creating the transport capacity and support which will enable the U.S. to deploy substantial numbers of troops to Third World trouble spots in very short periods of time... possession of an airlift force capable of deploying substantial numbers of troops quickly is an essential step in lengthening the nuclear fuze... [to seize the] "window of opportunity"...the commander must have the right forces at the right place and at the right time...the flexibility to maneuver to many places around the world is the essence of airlift.[5:123-124,131]

These words by General Duane H. Cassidy, Commander in Chief, Military Airlift Command, set the stage for the requirement for airlift to be able to deliver men and equipment as close as possible to the battle area as quickly as possible.

Motivation

Airlift requirements are rooted in Air Force doctrine. Maneuver is a principle of war emphasized by fundamental Air Force doctrine (8:ch2-5 to ch2-9).

> The use of maneuver allows commanders to position their forces in places and at times that surprise the enemy, so that the enemy forces are unable to counter, to respond effectively. To be effective, maneuver requires precise execution and timing, concentration of force and adequate logistical support [8:ch5-7].

Maneuver is the reason for airlift's existence. Airlift offers the mobility required to be decisive in war (3:7). This is evident in the definition of airlift's basic mission, taken from the *United States Air Force Fact Sheet Number 82-83* as cited by Bullard:

> ...to airlift personnel and material in support of military objectives for two missions: strategic and tactical. Strategic airlift (intertheater) is sustained air transportation between operational areas, or between the continental United States and overseas areas. Tactical airlift (intratheater) is deployment, airborne assault, air evacuation and air supply within an operational area.[3:7]

Lieutenant Colonel Bullard in a 1983 War College paper gave a good analogy to airlift. He stated that airlift capability should be "viewed as an unbroken circle" of continuous support for the user. He suggested that classifying airlift into strategic and tactical may obscure this capability; and, that air mobility should be thought of as "one system capable of traversing the entire circumference of the circle (3:8)."

With the importance of airlift established, the background leading up to current airlift requirements and how these requirements are measured is explored. Then an argument for using combat power delivered versus ton miles per day as a measurement of effectiveness for airlift requirements is provided.

Background

During World War II, airlift had finally demonstrated that it was a viable means of resupply. In

1945 the Air Transport Command's 3700 aircraft had airlifted 275,000 passengers and 100,000 tons of cargo worldwide (18:75). According to Dr. Leary in an article entitled *Strategic Airlift Past, Present, and Future,* the India-China resupply, called "The Hump," was a very dramatic example of what airlift can accomplish (18:75). General Cassidy states, "the Hump was the greatest airlift in history -- up to that time" (5:115).

Shortly after World War II airlift again demonstrated its enormous value when the Soviets blockaded West Berlin. The United States airlift resupply of West Berlin allowed defeat of the Russian blockade "without resorting to war" (18:77).

After WWII all of the DOD drew down its forces, but at the same time, crises around the world showed the United States that Communist Bloc aggression was a real threat (33:3-4). The United States undertook plans for "flexible response" to be able to deter this aggression. At the same time, budget constraints forced the Air Force to make reductions in its troop carrier wings (33:4).

In the early sixties, as the airlines were building up with modern fleets of aircraft, the Air Force was still being forced to draw down especially in the ability to airlift. It was suggested that the airlines could handle the military airlift requirements. In 1960 a special subcommittee of the House Armed Services

Committee was appointed to look into national airlift (18:78). The committee reported that airlift was a weapon system, that airlines would not fill the need, and that airlift was "seriously inadequate" (18:78).

Also in 1960, the Military Air Transport Service held an airlift exercise called operation "Big Slam." This exercise was highly successful in the amount of tons it moved but at the same time demonstrated large inadequacies of airlift (5:118-119;20:2). It seems the Air Force could move the troops but not in the time required by the Army. Also, the airlift was unable to move the equipment the troops would most likely need. The airlift fleet was only able to move one small tank, some artillery, and little ammunition (5:116).

Improvements were made with the purchase of new jet aircraft which increased our capability considerably, but with increased capabilities came increased commitments and a new shortfall developed (20:2).

Since the early sixties, our national strategy has been one of flexible response. Flexible response allows the President to choose the weapons and methods to respond to the enemy's advances. A key element of the flexible response strategy is mobility (5:120).

In 1981 the Congressionally Mandated Mobility Study identified an urgent requirement for the United States to develop the capability to airlift 66 million ton miles per day of cargo (5:120;18:81;29:58;30:2). Ton miles per day cargo capacity is figured by multiplying the speed of a particular aircraft by the number of hours per day the plane can be expected to fly, then multiplying this number by the maximum tons of cargo that can be hauled on the longest leg of the mission. These ton miles per day per aircraft are summed over all different types of aircraft available, to get an overall ton mile per day capacity for the entire airlift fleet. The minimum goal of 66 million ton miles per day was a fiscal compromise and did not fully satisfy any of the four scenarios used in the Congressionally Mandated Mobility Study (29:58;30:11).

All articles mention the 66 million ton miles per day requirement of the Congressionally Mandated Mobility Study, but a Government Accounting Office report, dated March 1987, brings out an important fact of the study. The report states:

> The goal of airlift, however, is to deliver combat troops and equipment as close to their final destination as possible, while maintaining unit integrity. In light of this goal, the CMMS concluded that DOD's intertheater airlift capability was lacking not only in quantity, but also in quality [30:11].

The GAO further noted that airlift needed the ability to deliver outsize cargo to small forward airfields, closer to the final destination (30:11).

In the *Annual Report to the Congress for Fiscal Year 1987*, Secretary Of Defense, Caspar Weinberger stated that the current Administration defense policy was to "ensure a balance of forces adequate for credible deterrence" (32:37).

Airlift capability adds to deterrence. The Government Accounting Office report stated that "the ability to move forces with sufficient equipment and supplies to distant locations may make military action by opposing forces less likely" (30:10). The same sentiment is held by Wendzel who believes airlift is a deterrent to aggression and aggression left unchecked creates more aggression (33:15-17). Ulsamer agrees and states that airlift just might be what is necessary to keep a conflict from escalating into a high level (29:58). He further asserts that having the capability to project the force just might deter "Soviet military adventurism"(29:58). General Cassidy says that, airlift should give commanders "unrestrained mobility and flexibility so that they may prevent battle or that they may surely win in battle" (5:131). The United States overall military strategy is one of deterrence and airlift plays a main role in this deterrence.

Weinberger points out the importance of the airlift fleet as part of the "Strategic Mobility Forces" (32:52). He states, "the inherent deployment flexibility of aircraft makes them a key element of our rapid deployment forces" (32:212). He discusses the importance of deploying our forces when and where they are needed (32:235). Weinberger also points out the plans for the C-17 aircraft to "deliver forces over intercontinental distances directly to austere forward locations" (32:236). These comments emphasize the importance of delivering the men and equipment directly to where they are needed, near the front. This "direct delivery" capability should greatly enhance our capabilities to project our forces around the world. Delivery would be by airdrop or airland at a forward air field (29:61-62).

In the *United States Military Posture FY 1987* publication, the Organization of the Joint Chiefs of Staff, also state the importance of airlift to the rapid deployment of forces (23:66). They further discuss the capabilities of the C-17 and the importance of delivering troops and all types of cargo to small austere airfields (23:66). These small austere airfields would be close to the final destination or to staging areas where forces would be assembled and then moved to the combat area (30:22).

It is very important for Department of Defense and airlift planners to have the capability to analyze and study airlift requirements. The previous discussions have shown the need for airlift to have the capability to directly deliver combat men and equipment to the combat area. With the procurement of the C-17 the United States will have that capability. The analytical models, used by planners of airlift, all use ton miles per day as measure of effectiveness for airlift (17). With the importance of direct delivery of combat units established, it will be helpful to planners to have a model that uses combat power delivered to the front as a measure of effectiveness for airlift.

The Model. In 1984 Army Captain James Cooke, an AFIT student, developed an analytical model to look at the rapid deployment of combat forces. This model looks at both the airlift capabilities and the combat units to deliver and finds the optimal mix of aircraft required to meet specified goals of force delivered (6:viii). There were 212 variables and 136 equations in Captain Cooke's model (6:viii). He also demonstrated how to use response surface methodology to do a full parametric sensitivity analysis.

Later that same year, Captain David Tate, another AFIT student, picked up on the same model and tried to incorporate some of the recommendations Cooke had made. Tate created a fortran-based interactive program to make the model user friendly. His front end to the model built the problem as he had intended; but, he could not get his routine to talk to the goal programing package he wanted to use to solve the problem (28:ch6-6). Tate's formulation of the model's constraints included a couple of improvements over Cooke's. Tate removed the restriction that only bulk cargo could be moved by intratheater airlift and the restriction that all units moving on their own power move at the same rate (28:ch7-3).

Tate made several recommendations for further research. First, he recommended that attrition of aircraft and troops be incorporated into the formulation. Second, a model representing the current inventory and capabilities should be developed. Third, more sensitivity analysis to include ranging of the right hand side values of the constraints should be accomplished. And lastly, the allocation routine PAGP, the routine that was supposed to solve the goal programing problem, should be corrected to work with the program he developed (28:ch7-4).

As follow on work in 1986, Major Raymond Haile took Cooke's methodology and built a model that maximizes the combat power delivered to the theater commander (14:ix). Haile's model uses 288 variables and 168 equations (14:ix). Haile's model also uses response surface methodology to do a sensitivity analysis on a Far Eastern theater of operations scenario (14:8).

Haile made recommendations for further refinements to the model. He noted that attrition, as included in his model, did not take into account the proper mix of aircraft type, mission type and period of the deployment and could be modeled better if specific threat scenarios were included in the model (14:135). Also, Haile pointed out that the mix of airlift forces recommended as a result of the model was highly scenario dependent and that a matrix generator to build the linear model would make it easier to change the scenario (14:135).

There are other areas where the model seems to display some weakness. First, the model was limited to four five-day periods, due to computer size and run time requirements, instead of a more desirable thirty one-day periods. Thirty days is considered the normal surge airlift requirement. Second, the model is restrictive in that it only considers one aerial port of debarkation (APOD) and one forward operating location (FOL) to be used during the surge airlift.

This model departed from maximizing total ton miles per day as the measure of airlift effectiveness and captured the real requirements on airlift by maximizing combat power delivered to the objective area. Combat power delivered attempts to capture how airlift can affect the battle by direct delivery of combat forces to the front. This model values forces delivered early and to the front more highly than forces delivered later and to rear areas (14:131-134). It captures the time value of forces delivered.

Statement of the Problem

The model developed by Cooke and refined by Tate and then Haile has not yet been implemented by Headquarters Military Airlift Command (HQ MAC) or for that matter by anyone in the DOD to analyze theater airlift requirements. Analyst in the HQ MAC Analysis Group have expressed interest in using this model. The problem is that the model in its current mathematical form is not user friendly and does not model attrition properly. The primary objective of this research is to answer the question, "How can the model be improved and packaged to increase the likelihood of acceptance into the HQ MAC Analysis Group's library of analytical methods?"

The Method

The linear programing model as presented by Cooke, Tate, and Haile exists in a form which requires a trained analyst to input raw data into the model, in whatever computer language he or she has available, and then interpret the raw output. Its use is limited by the fact that it is a stand alone model requiring a trained analyst to prepare and input data, run the model, and interpret the results. A preferred form to this model might be that of a decision support system.

A decision support system (DSS) is any system (in this case a computer based system) that assists the user with the making of decisions. The DSS has three components: a data base, a model base, and a man-machine interface (31). A DSS provides a user friendly atmosphere where the decision maker can study the problem with assistance from the model and the data base. A central theme in the design and building of any DSS is the adaptive design approach. The details of DSS design and the adaptive design approach are presented in the next chapter.

Research Objectives

1. To use adaptive design in building a decision support system (DSS) which incorporates this mathematical programing model.
2. To solicit specific user, HQ MAC Analysis Group, requirements.
3. To improve the modeling of attrition.
4. To adapt the model to accommodate a spreadsheet to input parameters and output results.
5. To develop a matrix generator to easily generate the input matrix, objective function, and right hand side for the model.
6. To identify the size of formulation required to expand the model from the current four five-day periods to thirty one-day periods.
7. To identify the requirements to expand the model to include more than one aerial port of debarkation (APOD) and forward operating location (FOL) .
8. To develop the formula that will determine the size of the problem and how the problem grows in size with each of the changes to be made.
9. To identify with the help of the user and a technique called concept mapping an initial problem to solve as an illustration of the application of this DSS.

Scope of Effort

The objective of this research is to build a prototype DSS to be used by HQ MAC Analysis Group. The identification of the initial problem to assist the decision maker with uses the concept mapping technique, and the identification of the overall design of the DSS uses the adaptive design technique. This DSS is a user-friendly front end for the mathematical model and utilizes a spreadsheet application package as boch DSS and matrix generators.

Changes to the formulation of the previously developed mathematical programing model are made when necessary. These changes were identified as either recommendations in the previous efforts, or were based upon interviews with HQ MAC analysts.

Organization

Chapter II is a literature review of the methodology and techniques used in developing this DSS. Chapter III is the first of three chapters that cover the three main parts of this DSS. This first part is the data base used in the DSS. The chapter describes the data used for the model, the origin of the data, and the format of the data as used in the DSS. Chapter IV describes the model base used in this DSS. Detailed descriptions of the mathematical programing model and the improvements made to earlier formulations are given. Chapter V discusses the third part of the DSS, the man-machine interface.

This chapter presents the attributes of this DSS that make it user friendly, such as the menus and explanations of the menu selection built into this DSS. Chapter VI presents a discussion of the findings from the implementation of the kernel problem. It also contains a summary of conclusions and recommendations.

II. Methodology

Introduction

This chapter presents a literature review of the methodology and techniques used to develop this DSS. It begins with the definition of DSSs. Next, a discussion of why a DSS is needed for the previously developed mathematical model is presented. The chapter continues with a presentation of the characteristics of DSSs and is followed by a discussion of the adaptive design process. The presentation on adaptive design includes the four stages of adaptive design and the key concepts involved in those stages. This chapter concludes with a discussion of the three components of the DSS.

What is a Decision Support System?

Sprague and Carlson in their book *Building Effective Decision Support Systems,* describe the real definition of a DSS as being somewhere between "interactive computer-based systems that help decision makers utilize data and models to solve unstructured problems," a restrictive definition, and "any system that makes some contribution to decision making," a broad definition (26:4). AFIT Lt Col Skip Valusek in a course on Decision Support Systems defines a DSS as a system that supports the mental processes of judgement and choice (31). With a definition of DSS in mind the next question is why is one needed in this case.

Why Decision Support System?

All three models developed by Cooke, Tate, and Haile required the use of a mainframe computer at AFIT. Cooke and Haile both relied on the mainframe to solve their mathematical formulation program and to develop the response surface equations to use in their analysis. Their use of a mainframe made using the model difficult for a number of reasons. For example, an analyst had to be very familiar with the specific package being used. Also, putting the data in the required format was very time consuming. In fact, one of the reasons why Cooke and Haile included response surface equations was to speed up the process of making predictions with the results of their models (6:96;14:11-12). Tate used the mainframe for the FORTRAN-based front end to his model. Tate's objective was to build a user friendly interactive front end that allowed the input of data either interactively or through data files. Had his program worked with the routine required to solve the mathematical goal programming formulation the input of data would have been easier although time sharing and output analysis would still require a considerable amount of time (28:ch7-4).

The main objective of the current research effort is to develop a microcomputer-based Decision Support System (DSS) to support Air Force and other interested DOD decision makers. Cooke recommended that the model be developed into a user-friendly computer package (6:132). Haile recommended that a matrix generator be developed to build the input matrix for the linear program (14:135). This current methodology incorporates these recommendations and then goes further by pursuing a number of DSS concepts.

The reason for developing this DSS on a microcomputer is because of the proliferation of microcomputers in the Air Force. No longer does analysis have to be restricted to studies and analysis organizations with access to mainframe computers. Analysts can work with a DSS such as the one developed in this thesis at literally thousands of locations where microcomputers are available. Also, DSSs allow mathematical models to be used by nonanalyst managers and novice computer users. For example, the current DSS might be used by Air Force planners trying to plan how many sorties of what type aircraft are required, or by Army planners trying to decide what mix of army units is required to maximize firepower and meet the minimum required anti-tank and defensive frontage capabilities. With the motivation for the development of this DSS established, the next section discusses the characteristics of a DSS that this research exploits.

Characteristics of DSSs.

Sprague and Carlson list four characteristics of DSSs. Each of these characteristics and how the DSS developed in this research fits these characteristics will now be described. DSSs tend to be aimed at the semi-structured to unstructured, underspecified problems (26:6). This characteristic means that it is hard to say ahead of time what the problem is and how exactly to solve it. The current DSS is originally being designed to answer a specific kernel problem (a problem identified as the initial problem to help the decision maker solve). Other uses of the DSS and other problems to be solved with this DSS are difficult to specify ahead of time.

A second characteristic is that a DSS attempts to combine the use of models with traditional data access and retrieval (26:6). The DSS developed in this thesis uses data bases to supply the parameters used in the linear program model. For example, the numbers of aircraft, capabilities of aircraft, attrition rates, and number of units available for the deployment are all parameters that are in the data base and used by the linear programming model.

The third characteristic is that properly constructed DSSs are interactive and easily used by noncomputer people (26:6). The current DSS, which uses microcomputer CRT and keyboard for inputs and CRT, disk drive, or printer for outputs, is interactive. The development of menus to lead the user through the data bases and the output of the linear programming model requires the user to know very little about the software used for this DSS. The menus appear at the top of the spreadsheet and an explanation of the highlighted menu item appears on the line directly below the menu. The user can select a menu item by either using the first letter of that item or by using the arrow keys to highlight and return key to select. A data base item can be changed using the arrow keys to select the item and then typing the new entry, which then appears on the top line of the spreadsheet, upon pressing return the change is inserted. A notepad, for the user to leave notes to himself, and a hookbook, for the user to leave notes for the system designer and builder, are included and can be selected from any menu. These two capabilities are not only user friendly but also help satisfy the next characteristic of a DSS, that of being adaptable.

The last characteristic of a DSS that Sprague and Carlson identify is that a DSS is flexible and adaptable to changes in the decision making environment and approach of the user (26:6). The largest stumbling block for the adaptability of any system is the communication between the user, the designer, and the builder of the system (16:16-22). The notepad and hookbook described earlier allow the user to keep track of his thoughts over a period of time and allow the user to leave messages for the system designer and/or builder. Another aspect of the current DSS that increases its adaptability is that as new uses are discovered a new menu can be be added and a new macro can be created to accomplish the new task. This can be done without affecting any previously developed menus or macros. This modularity was identified as a necessary attribute for the selection of a DSS generator (the software and hardware used to create the DSS) in a article entitled *Adaptive Design for DSS Development* (1:27). This fourth characteristic of a DSS, adaptive design, is really the heart of the entire DSS design process.

Adaptive Design

The primary method for identifying changes to be made in the DSS will be the adaptive design approach. Adaptive design consists of taking a crude model, using it and subsequently improving it through the four stages of design. Sprague and Carlson point out that in adaptive design these four stages -- requirements analysis, design, development, and implementation -- are iteratively repeated in a relatively short time (26:15). The amount of time is dependent on the system being developed; but for example, if normal computer system development would take say three to five years then an adaptive design cycle should take say three to seven months (31).

Requirements Analysis. The first stage of the four stages of development is requirements analysis. One method that can be used for requirements analysis uses the idea of concept mapping to identify the kernel problems.

Concept Mapping. Capt Mike McFarren developed the basis, justifications, and procedures for concept mapping in problem analysis (22:14-16). He described concept mapping as a way to "identify the key factors and ideas of a problem space...[and show] their relationships to each other (22:40)." Concept mapping is used to identify the kernel problem from which to begin the adaptive design. The procedures for concept mapping consist of interviewing the user to capture the user's understanding of the problem and mapping the user's understanding of the problem on paper or chalkboard. To map the concepts the interviewer places the events (concepts) identified by the user in circles or rectangles on the board and connects the events with linking words obtained from the user. After the concept map is completed, the key events, the kernels, can be identified by the user. The user identifies one or more of the kernels to becomes the initial requirement for the design of the DSS during the first iteration of adaptive design. For this DSS an interview was conducted with Capt Mark Fowler, an analyst with the HQ Military Airlift Command's Analysis Group (12). A concept map was constructed and appears as figure 1. Two kernels were identified as initial problems for the DSS to address.

Kernels for this DSS. The initial problems identified for development in this DSS were both related to the allocation of airlift resources. The first problem would be to study how the model would use the number of each different aircraft available to fly different types of missions. These different types of missions include intertheater (US to APOD), intertheater (US to FOL) airland, intertheater (US to FOL) airdrop, and intratheater

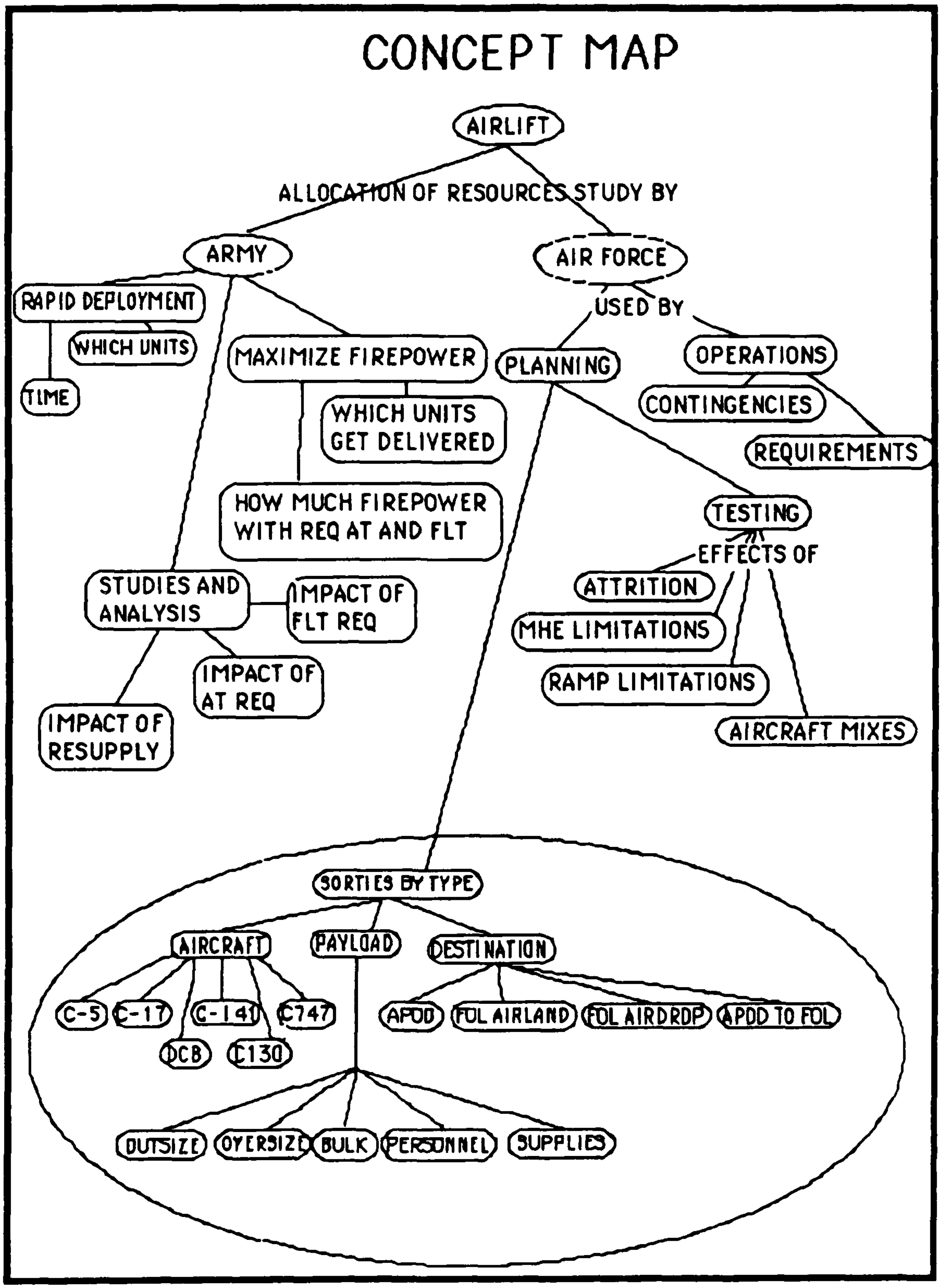

Figure 1. Concept Map

(APOD to FOL). The second kernel was to study the problem of determining how the aircraft are used to satisfy different cargo requirements. The question was to find out how many sorties of what type cargo was required in each period by each aircraft type. These types of cargo include outsize, oversize, bulk, personnel, and supplies.
A further discussion of the results of the DSS designed for these kernel problems is in chapter VI.

Design. After the kernel problem or problems have been identified as the initial requirement for the DSS, the design phase begins. A very effective technique for the design of the DSS is the ROMC approach developed by Sprague and Carlson (26:101-107).

ROMC Approach for Design. The four components of the ROMC approach are representations, operations, memory aids, and control mechanisms (26:101-107). These components make up an approach that allows the DSS design to identify capabilities while being process-independent (26:101). In other words the DSS is designed to allow flexible approaches so that multiple users can use the system to suit their decision processes. The next four sections cover each of these components and how this DSS design uses that approach.

Representations and Storyboarding. Representation is very important because it has to do with communication. Thoughts are often most easily expressed in the form of a picture. Relationships can be expressed and communicated quickly in the form of a graph. All communication is done in terms of some sort of representation be it words, pictures, graphs, or numbers (26:102). Representation is the means by which the user through menus, commands, and data base changes communicates information with the machine and the means by which the machine through screen displays communicates information to the user. An interesting technique, new to computer system design, for performing the representation phase of system design is storyboarding. Andriole states that, "a storyboard is a sequence of displays that represents the functions that the system may perform when formally implemented (2:3)." A storyboard becomes a powerful tool in the representations phase when the storyboards are designed with the user's inputs or even by the user himself. At this phase it may be preferable if the system builders, the information system personnel, were not involved with the design (31). To capture the true requirements for the system, the concept map identifies the kernel problem to solve and the storyboard identifies the screen displays that the user can understand and gain the most information from. After these steps are complete, the system can be handed over to the system builders so the first prototype can be built. For the DSS developed here the storyboard consists mainly of the display of the menus, the data tables, and the output. The storyboard for this DSS is presented in the figures throughout this thesis. The data-base storyboards are in chapter III. The menus and output storyboards are in chapter V.

Operations. The operations component of the DSS design approach are the manipulations required of the representations and should correspond to the operations that the user must go through to make a decision. These operations fall into three human information processing categories which are intelligence, design, and choice (26:103). Intelligence operations are operations such as data gathering and validating, problem diagnosis and structuring, and objective identification (26:104). Design operations include data manipulation, generating alternatives and reports, and quantifying alternatives and objectives (26:104). Choice operations include generating statistics and simulating results of alternatives, choosing among alternatives, and explaining alternatives and choices (26:104). These operations should be considered and included in the DSS when warranted. This DSS incorporates many of these operations. Operations are provided for updating all the data bases. The data is automatically manipulated by the Lotus 123 spreadsheet to build the matrix for the linear programming software. The output of the model is again manipulated by the Lotus 123 spreadsheet to present the results in a way to answer the kernel problem. These operations are built into the DSS and are transparent to the user.

Memory Aids. Memory aids are necessary because the average human being is capable of storing only seven plus or minus two pieces of information in short term memory and must exert a large amount of effort to store information in his or her long term memory (25:81-85). What this means to the designer of a DSS is that for the DSS to be user-friendly the DSS should not require the user to remember large amounts of information such as commands or even to remember their location in the DSS. The DSS needs to have memory aids that keep the user on track, where the user would like to be, freeing up the user's short term memory to work on current tasks. In the DSS developed for this thesis menus are used to lead the user through the DSS, and prompts on the screen displays remind the user of the commands to return him to certain menus. Notepad and hookbook areas are provided as a way for the user to jot down thoughts that come to him or her thereby freeing up the user's short term and long term memory.

Control Mechanisms. Control mechanisms are simply aids that help the user control the DSS (26:106). These aids include but are not limited to menus, libraries, help menus, training programs and operations that can change any default values of the DSS (26:106-107). The menus in the current DSS are the main control mechanism that help the user operate this DSS. On the line under the menus appears an explanation of the function of the highlighted menu item. A short user's manual also accompanies this DSS to explain how to get into and out of the DSS and how to run the model.

Development Phase. The DSS is actually built in the development phase. Sprague and Carlson point out three typical approaches to the actual development of the DSS. The first of these is what they call the "quick-hit (26:61)." This approach uses tools that are currently available or can be purchased easily to build the first DSS. This approach can lead to a throw away DSS that is only good for one purpose. When the next iteration is identified a new DSS might need to be built (26:61). The next approach is the "staged development approach (26:61)." This is an iterative approach and seems to fit best with the adaptive design approach. One disadvantage of this approach is that more time is spent on the initial development building a more universal DSS that allows for easier follow on changes. The last approach actually builds a complete DSS generator and is called the "complete DSS (26:61)" approach. This complete DSS can take a very long time to develop, six to ten years, and has the greatest risk of technological obsolescence (26:63). Also, with a system taking that long to develop, requirements determination would be next to impossible. The approach used is situation and organization dependent.

In the development of this DSS the staged development approach was used. All four stages of design were completed in a relatively short time with the initial DSS given to the user to use and provide feedback to the designer. This approach was in line with the adaptive design approach of quick iterations of the four design stages.

Staged development of a DSS allows for changes in the DSS to be identified and included in subsequent iterations of the DSS. To facilitate building the DSS and making it easily adapted a DSS generator had to be selected. The generator selected had to be able to handle the three components of the DSS.

Components of a DSS. The three components of a DSS are the data base, the model base, and the man-machine interface (26:29). The data base component consists of the data and the data base software to manage the data. The model base is the model or models in the DSS and the software to run those models. These models can be analytical, simulation, or any model that manipulates the data bases and provides the user with information. The man-machine interface is the dialog component of the DSS. As Sprague and Carlson point out, "from the DSS users' point of view the Dialog is the System (26:29)." For a DSS to work correctly the generator selected must be able to coordinate the three components in a manner that is relatively transparent to the user.

In the development of this DSS the model base was the linear programming model that had been previously developed. The data base for this DSS consists of the parameters that are inputs to the model. The man-machine interface is very DSS generator specific and this led to a search as to what software packages were available for the micros at AFIT. In order to run the linear programming model on the Zenith 248 microcomputers it was discovered that the only software initially available was LP83 from Sunset Software a "professional Linear Programing Package (27)." A DSS generator had to be found that was compatible with LP83.

Lotus 123 was picked as the DSS generator because: 1) it was availiable at AFIT, 2) it was identified as being compatible with LP83 and 3) it seems to be the industry standard for spreadsheet packages and many users are familiar with basic operation of Lotus.

During the process of building the DSS and validating the spreadsheet it was found that LP83 could not solve this linear programming formulation. A newer version of Sunset Software's linear programming software called XA was acquired and did work with the spreadsheet (27:4.0-4.51). XA was used for the remainder of this research.

Implementation Phase. The implementation phase is the last phase in the adaptive design approach to creating a DSS. Basically, implementation is when the user is given the DSS to use and to critique. Hopefully the user is enthusiastic about acquiring the DSS since he or she was involved in the earlier phases. The DSS developed in this thesis has been delivered to the Analysis Group at HQ MAC and the recommendations made for the next iteration of the DSS are discussed in chapter VI.

Summary

This chapter has described the methodologies used in the creation of a DSS. The chapter began with a discussion of why a DSS was developed followed by a description of what a DSS is and the techniques used to build one. The three components of a DSS, the data base, the model base, and the man-machine interface were introduced. The next three chapters will describe each of these components for the current DSS developed.

III. Scenario and Data-Base Development

Introduction

This chapter begins with a discussion of the scenario which this DSS supports. This generic scenario and the assumptions and limitations on the various players in the model are discussed first.

The Far Eastern theater scenario used for this DSS is discussed after the generic scenario. Next, an introduction to the data base required in this scenario and an explanation of the data base tables is presented. This data base is used by the DSS to input the parameters to the mathematical programming model. Each table is presented in its storyboard (screen display) form with explanations of where the data originated. There are thirteen tables in all.

Scenario

The scenario presentation is developed in four parts. The first discussion is about the locations involved in the deployment and how the men and equipment can be deployed to these locations. The second part of the scenario involves the assumptions about the aircraft used in this DSS. Part three discusses limitations presented by airfields in this scenario. The last part presents limitations on the units to be deployed in the scenario. The explanations of how these assumptions and limitations affect the mathematical formulation are covered in the next chapter, the model base chapter.

Deployment Assumptions. This DSS supports a deployment from one location in the US to one aerial port of debarkation (APOD) with subsequent movement to a forward operating location (FOL). In this context the APOD is considered to be in the theater of operations but near the rear areas of the troops, the FOL is considered in the theater but nearer to the front edge of the troops. Direct delivery of troops and equipment to the FOL is also possible for certain aircraft. The deployment to the APOD is by airland missions only. Deployment from the US to the FOL is by either airland or airdrop and the model decides the proper mix to optimize combat power delivered to the objective area. Deployment from the APOD to the FOL is accomplished by any of three methods, either by airland or by the troops moving to the front on their own power or by equipment being moved by deployed truck units. Again the model decides the proper mixes of movements to optimize combat power delivered.

The timeframe of the deployment is also an assumption of this DSS. This DSS assumes that the first twenty days of a deployment are the most critical as far as airlift is concerned. After that time sealift can pick up most of the lift requirements. It also assumes that the twenty days can be modeled by linking four five-day periods (14:70).

Aircraft Assumptions. In this scenario different aircraft have the capability to accomplish different missions. These missions are: intertheater airland - US to

APOD, intertheater airland direct to the front - US to FOL, intertheater airdrop direct to the front - US to FOL, and intratheater airland - APOD to FOL. There are six different types of aircraft used for the deployment in this scenario. Three of these aircraft: C-5, C-747, and DC8 are only considered capable of intertheater airland at the APOD. The C-17 and the C-141 are capable of all four types of missions and the C-130 can only fly intratheater - APOD to FOL missions. Individual aircraft and their characteristics can be changed but the mission capabilities are fixed due to the formulation of the linear programming model. For example, if the C-130 capabilities were replaced with the capabilities of a different aircraft this DSS would still assume the new aircraft was only capable of intratheater airlift. If the mission capabilities had to be changed, then the mathematical formulation would have to be changed.

Attrition can be set by aircraft and by mission type and is expressed as percent of missions flown that are expected to be lost.

Airfield Assumptions. There are two major limitations of the airfields included in this DSS. The first limitation has to do with parking aircraft at both the APOD and the FOL. The maximum number of each type of aircraft that can be parked at each airfield is input to the DSS and the model keeps track of parking space used up and restricts parking to what is available. The second airfield limitation is with the material handling equipment (MHE) available at the APOD and FOL. These limitations are input as number of standard pallets of cargo capability per day at the APOD and the FOL.

Another limitation implicit in this DSS is that all aircraft sorties are spaced evenly throughout each period. Sortie generation, parking restrictions, MHE restrictions and the like are based on evenly spaced flows of aircraft.

Unit Assumptions. There are eight different units considered for deployment in this DSS. They are: 82nd Airborne, 82nd HQ Unit, Artillery, Mechanized, Air Assault, F-16, Transportation and ALCE units.

The first assumption regarding deployable units is that certain units are to be deployed only to certain areas. The HQ, Transportation, and F-16 units are delivered only to the APOD. These three types of units work out of the APOD. The F-16 units are the only units whose combat power is counted while at the APOD; because, they fly their missions out of the APOD. The Airborne, Artillery, Mechanized and Air Assault units must make it to the front before any portion of their combat power is counted. The Transportation, and ALCE units are not given any values for the three measures of combat power; although, the deployment of Transportation and ALCE units allows greater delivery of other units. The DSS decides if the cost, in airlift requirements, to move Transportation and ALCE units is worth the gain in delivery capability.

The HQ units are not given combat power values, but they are required with the delivery of Airborne units.

The Airborne and Mechanized are considered combat units and the Artillery and Air Assault are considered combat support. The DSS requires there to be at least as many combat units as there are combat support units delivered to the FOL.

This DSS can support any scenario that fits within the assumptions listed above. Different scenarios are developed by changing the parameter inputs to the DSS. This thesis has developed one scenario built around a Far Eastern theater of operations.

Far Eastern Theater Scenario

The Far Eastern theater scenario and data base required for this scenario is discussed in this section. The scenario assumptions are presented first followed by an introduction of the data base tables.

Scenario Assumptions. The scenario in this DSS is based on the following assumptions:

1) All intertheater aircraft will use Travis AFB as the staging base for departure from the CONUS.
2) The APOD is Kwangju AFB Korea and the FOL is Suwon AFB Korea.
3) The available units to deploy are assumed to be at Travis AFB and ready to upload.
4) All bases are operational 24 hours a day.

These are the basic assumptions of this scenario other assumptions are presented as the data base tables are described.

Data Base Tables and Assumptions. There are thirteen data base tables. These tables are grouped in a logical fashion to help the user remember where certain parameters are in the data base.

In all of the thirteen tables a column contains different data values of a data type. For example, bulk cargo carrying capability would be one column and in that column would be the different values of that parameter for the different aircraft in the scenario. The rows in the tables contain different parameter values for different aircraft, units, or airfields.

The name given for each parameter in the data base is the Lotus 1-2-3 range name used to generate the matrix for the mathematical formulation. The capital letters are the range names, the lower case letters a, j, and z, when used as part of the range name, refer to the corresponding letters at the top of the columns. For example, the range name for the parameter for the intertheater utilization rates for the C-5 is aC5z, where the a and z come from the top of the column and a=UTE and z=AP, thus the range name is UTEC5AP. These range names become important only when decoding or changing the mathematical formulation.

There are four major groupings of tables; these groupings are: aircraft, airfields, units, and requirements. In the following sections, each group is presented along explanations of where the data originated and the assumptions underlying the data.

The data base tables are presented in the same form as the CRT display in the DSS; therefore, the reminders as to which commands take the user to which menus are also in the tables.

Aircraft Data Base. There are five different screen displays for the aircraft parameter portion of the data base. These five screen displays are the aircraft available, usage rates, performance capabilities, cargo capabilities and attrition displays. The aircraft available screen display is shown in Table I.

Table I

AIRCRAFT AVAILABLE

Name	Number	Description
NUMC51	40	C5A/B aircraft availiable, 60th MAW, Travis AFB
NUMC171	40	C17 aircraft used in this run of the model
NUMC1411	110	C141's from the west coast, 62nd, 60th, 63rd
NUM7471	30	CRAF 747s
NUMDC81	20	CRAF DC8s
NUMC1301	60	C130s used in this run of the model
NUMTAC	18	Number of fighters assigned to each fighter unit

alt a	for menu to change more aircraft data
alt c	for change menu
alt m	to return to main menu
alt p	use to print, highlight with arrow keys press return.

The numbers of the various types of operational transport, C-5, C-141, and C-130, aircraft available for this deployment were assumed to be the numbers of the various aircraft available to 22nd Air Force. 22nd Air Force is responsible for airlift in the Far Eastern part of the world. The number of C-17 and Civil Reserve Air Fleet C-747 and DC8 used in this table were set as possible numbers for this scenario.

Table II contains the aircraft usage rates used in this DSS. The usage rate is the days required for an aircraft to complete a complete round trip of a particular mission.

Table II

AIRCRAFT USAGE RATES

Name	Inter j=er	Intra j=ra	Description Days required for round trip mission
INTjC5	2.2	N/A	C5A/B days required
INTjC17	2	0.2	C17 days required
INTjC141	2.1	0	C141 days required
INTj747	2	N/A	CRAF 747 days required
INTjDC8	2	N/A	CRAF DC8 days required
INTjC130	N/A	0.25	C130 days required

alt a	for menu to change more aircraft data
alt c	for change menu
alt m	to return to main menu
alt p	use to print, highlight with arrow keys press return.

The usage rates for each aircraft must be figured using average ground speeds and the lengths of various mission legs in the deployment scenario. For this scenario the aircraft departing Travis AFB would make an enroute stop at Elmendorf AFB for fuel and continue on to either the APOD or the FOL. After offloading the mission would continue on to Yokota AFB for refuel and crew change and then proceed back to Travis again through Elmendorf. Standard ground times and expected maintenance delay times are included to give a total expected round trip time for each aircraft (14:72).

Table three contains the parameters for the aircraft performance capabilities.

Table III

AIRCRAFT CAPABILITIES

Name	--Utilization Rates a=UTE (hrs/day)- --- Intertheater - to APOD z=AP	to FOL z=FO	Intra z=IN	Airdrop z=AD	True Airspeed (knots) a=SPD	Ground Times (hours) a=GTM	Ground Times at FOL a=GTMF
aC5z	12.5	N/A	N/A	N/A	423	3.25	N/A
aC17z	15.65	15.65	8.1	15.2	440	2	1.75
aC141z	12.5	10	10	8	410	2.25	2
a747z	10	N/A	N/A	N/A	450	3.6	N/A
aDC8z	10	N/A	N/A	N/A	440	2.8	N/A
aC130z	N/A	N/A	4	N/A	270	2.25	1.5

alt a   for menu to change more aircraft data
alt c   for change menu
alt m   to return to main menu
alt p   use to print, highlight with arrow keys press return.

The data for the utilization rates and airspeeds used in this scenario was extracted from the US Air Force Airlift Master Plan (9:A-10). The ground times for both the APOD and FOL are typical ground times (14:79).

Table IV provides the parameters that pertain to the aircraft cargo capabilities. This table includes, for each aircraft, how much of what type of cargo can be carried, how many standard pallets can be carried, and the ease of offload factor that converts different types of cargo to equivalent number of pallets of offload capability required.

Table IV

AIRCRAFT CARGO CAPABILITIES AND EASE OF OFFLOAD

Name	Outsize (tons) z=OUT	Oversize (tons) z=OVR	Bulk (tons) z=BLK	Personnel (people) z=PER	Max Pallets Airland a=MHE no	Max Pallets Airdrop a=ADC
aC5z	73.4	78.1	82.8	340	36	N/A
aC17z	45	48	50	102	18	10
aC141z	N/A	20	23	152	13	8
a747z	N/A	59.2	99.1	0	36	N/A
aDC8z	N/A	N/A	41.4	219	0	N/A
aC130z	N/A	N/A	13.2	64	6	N/A

Ease of offload standardizing factor a=EAS

aC5z	0.05	0.2	1	0.05		
aC17z	0.05	0.2	1	0.05	alt a	for aircraft menu
aC141z	0.05	0.2	1	0.05	alt c	for change menu
a747z	0.05	0.2	1	0.05	alt m	to return to main
aDC8z	0.05	0.2	1	0.05	alt p	use to print
aC130z	0.05	0.2	1	0.05		

The data for the cargo capabilities of the C-5 (7:9), C-141 (7:13),C-747 (7:20), DC-8 (7:20), and C-130 (7:A4-8) were extracted from Air Force Regulation 76-2 and are the average tons carried per aircraft. The number of pallets per aircraft was also extracted from AFR 76-2 (7:A4-10). The C17 numbers were not published but were obtained from an interview with the chief C-17 loadmaster at HQ MAC (19).

A value of one for the ease of offload standardizing factors of table IV indicates that enough material handling equipment (MHE) must be available to offload the maximum number of standard pallets that the aircraft can carry. For outsized cargo which is considered to be 100% rolling stock, such as trucks and tanks, only minimal MHE is required to offload, thus the .05 factor for outsize cargo. Oversize cargo is considered to be 80% rolling stock thus the .2 for standardization factor under the oversize column. Bulk is considered completely palletized and gets a one for its factor. And lastly, personnel which can walk off the aircraft on their own but require their baggage to be removed the aircraft receive a factor of .1 (12).

The last table of aircraft parameters, Table V, contains the attrition values used in this DSS.

Table V

ATTRITION

Name	to APOD z=AP	to FOL z=FO	Intra z=IN	Airdrop z=AD
	Attrition Rate a= ATRT			
aC5z	0.001	N/A	N/A	N/A
aC17z	0.0005	0.0025	0.005	0.005
aC141z	0.0015	0.005	0.01	0.01
a747z	0.001	N/A	N/A	N/A
aDC8z	0.001	N/A	N/A	N/A
aC130z	N/A	N/A	0.005	N/A

alt a   for menu to change more aircraft data
alt c   for change menu
alt m   to return to main menu
alt p   use to print, highlight with arrow keys press return.

The attrition rates were based upon a discussion with Maj William Ewing of HQ MAC/AG (10). He has studied attrition and has published a paper on survivability enhancements to the airlift fleet (11). While his study shows many factors go into attrition rates, Maj Ewing felt that the rates in the table were representative of rates that could be expected in this scenario.

Airfield Data Base. The airfield data base group of tables contains three screen displays. These three screens are: airfield distance, airfield ramp capacity, and material handling equipment. Table VI contains the distance table.

Table VI

DISTANCE TABLE

Name	Distance (nautical) (miles)	
DISAPFO	200	Distance from the APOD to the FOL
DISUSAP	4440	Distance from the US to the APOD
DISUSFO	4640	Distance from the US to the FOL

alt f	for airfield change menu
alt c	for change menu
alt m	to return to main menu
alt p	use to print, highlight with arrow keys press return.

The distances in Table VI are approximate and are taken from the Airlift Planning Guide (15:38).

Table VII contains the airfield ramp capacity parameters. The numbers in the table were obtained from the HQ MAC Maximum on the Ground (MOG) listing (21)

The last table in the airfield group, Table VIII is the material handling equipment table. The data on this table are the number of pallet equivalents per day of cargo capacity assumed to be at the APOD and FOL.

Table VII

AIRFIELD RAMP CAPACITIES

Name	Location	
	Kwangju	Suwon
Airfield	RKJJ	RKSO
Identifier	(APOD)	(FOL)
	a=NPRKA	a=NPKF
aC5	8	3
aC17	15	14
aC141	12	12
a747	8	3
aDC8	12	12
aC130	15	14
aF16	40	N/A

alt f for airfield change menu
alt c for change menu
alt m to return to main menu
alt p use to print, highlight with arrow keys press return.

Table VIII

MATERIAL HANDLING EQUIPMENT

Name	---- Pallet Equivalents / day	---Comments
MHEAPOD	1000	at the APOD
MHEFOL	500	at the FOL
MHEALCE	500	ALCE addition

alt f for airfield change menu
alt c for change menu
alt m to return to main menu
alt p use to print, highlight with arrow keys press return.

Units Data Base. This unit data base group of tables includes three tables. These three tables are the deploying unit requirements table, the deploying unit capabilities table, and the unit indicators and combat value table.

The first unit data base table, Table IX, contains the parameters for the airlift requirements to move the different deployable units in the scenario. These requirements are given in tons of outsize, oversize, and bulk cargo and numbers of people.

Table IX

DEPLOYING UNIT REQUIREMENTS

Name	Number Available a=UNIT no z	outsize z=OUT	oversize z=OVR	bulk z=BLK	personnel z=PER	Daily Supply Consumed a=TONC no z
		--------- Cargo	type a = TON	---------		
aAB82z	9	0	197.3	54.9	697	32.76248
aHQ82z	3	0	81.6	15.1	101	4.747505
aAASSz	4	122	523.1	54.1	277	13.02038
aARTz	3	41.4	361.1	44.8	188	8.83694
aMECHz	5	3770.3	1237.7	108.6	543	25.52371
aF16z	1	0	168	85.4	423	19.88311
aTRKz	3	0	1504.7	189.1	472	22.18636
aALCEz	2	0	100	40	150	7.05075

alt u for menu for unit changes
alt c for change menu
alt m to return to main menu
alt p use to print, highlight with arrow keys press return.

The data in Table IX for the deployable army units are taken from the MAC pamphlet 50-13, the Airlift Planning Guide. The 82nd Airborne units to be deployed were the infantry battalion of the Airborne Division (15:8). The HQ units were the Headquarters and Headquarters Company of the Airborne Division (15:8). The Air Assault units were the Attack Helicopter Battalions of the Air Assault Division (15:6). The Artillery units were the Division Artillery of the Mechanized Division (15:12). The Mechanized units were the Tank Battalions of the Mechanized

Division (15:12). Lastly, the Transportation units were the Supply and Transportation Battalions of the Airborne Division (15:8). The data for the F-16 units including the supply consumption was determined from a discussion with Capt Golden of Hq MAC (13). The data for the ALCE and its supply consumption was determined to be representative of a typical ALCE that might be deployed in this scenario and was obtained through a discussion with Chief Burkhardt of HQ MAC (4).

The second table in this group, Table X, is the Deploying Unit Capabilities screen display. The first three columns of this table show the units inherent combat power values for the three measures of combat power: firepower, anti-tank capability, and front line trace.

Table X

DEPLOYING UNITS CAPABILITIES

Name	- Measures of Effectiveness			Transport to the Front Capabilit	Distance Unit Can Travel in one day	Periods APOD to FOL DISAPFO/TVLz /PL
	Fire Power a=FP	Anti-Tank Strength a=AT	Defensive Frontage a=FLT	a=TMC	a=TVL	a = PTVL
aAB82	4	19.5	4	0	20	4
aHQ82	0	0	0	0	20	4
aAASS	6	28.5	4	0	18	4.444444
aART	3	3	0	0	12	6.666666
aMECH	8	40	6	0	14	5.714285
aF16	8	36	0	0	0	ERR
aTRK	0	0	0	182	40	2
aALCE	0	0	0	0	0	ERR

alt u for menu for unit changes
alt c for change menu
alt m to return to main menu
alt p use to print, highlight with arrow keys press return.

The numbers for the three combat power values were taken from Cooke. His data for front line trace came from Army doctrinal publications; and the data for anti-tank was figured by counting the TOW and DRAGON anti-tank systems the units owned, assigning a value of one for each TOW and .5 for each DRAGON. The combat firepower values were determined from relative firepower scores of the units as used in an Army War College force-on-force war game (6:81).

The ton-mile lift capability of the Transportation unit is in the next column and to its right the distance each unit can travel in a day is given. The periods it takes a unit to travel from the APOD to the FOL is in the last column and is figured automatically when the distance from APOD to FOL and the distance a unit can travel in a day are set.

The next table in this group of screen displays, Table XI, contain the values for combat value over time. The DSS uses Lotus 123 as the DSS generator, and due to the size limitations of the Lotus spreadsheet when used with MS DOS the DSS had to split into two spreadsheets. Some of the constraint equations had to be placed on the second spreadsheet and this table includes reminders to the user to make changes for rigger capacity, and the combat and airdrop indicators on the other spreadsheet.

The combat value over time multipliers emphasize the fact that firepower delivered early is worth more than firepower delivered later. The values used for CPI in

Table XI were taken from the work of Cooke (6:83).

Table XI

```
COMBAT VALUE OVER TIME     INDICATORS
================================================================
  Name      Period      Value     Name     Airdrop         Combat Ind
                       factor             Indicator         1 combat
---------------------------               1=yes            -1 support
  CPI1        1          2.5              0=no              0 neither
  CPI2        2          1.8              a=AD    ** NOTE *  a=CI
  CPI3        3          1.3 ------------------------------------
  CPI4        4          1.1 aAB82             1
---------------------------aHQ82             1
RIGGER CAPACITY              aAASS             0          Must be changed
RC          ** NOTE **       aART              0          on part B
Must be changed on part B    aMECH             0          spreadsheet
spreadsheet                  aF16              0
                             aTRK              0
                             aALCE             0
alt u    menu for unit changes
alt c    for change menu
alt m    to return to main menu
alt p    use to print, highlight with arrow keys press return.
```

The last table in this group is Table XII. This table is on the output spreadsheet.

Table XII

```
COMBAT VALUE OVER TIME, RIGGER CAPACITY, AND UNIT INDICATORS
================================================================
AIRDROP CAPACITY             DEPLOYED UNIT INDICATORS
IN PALLETS          Name      Airdrop           Combat     1 combat
NAME      a=AD                        1=yes               -1 support
aC17           10                     0=no                 0 neither
aC141           8                     a=AD                  a=CI
                             ------------------------------------
                             aAB82             1                1
RIGGER CAPACITY              aHQ82             1               -1
IN PALLETS                   aAASS             0                1
RC            250            aART              0               -1
PERIOD LENGTH                aMECH             0                1
PL              5            aF16              0                0
                             aTRK              0                0
                             aALCE             0                0
alt m    for main menu
alt o    for output menu
alt g    for graph menu
```

This table contains the maximum number of pallets that the two aircraft capable of airdrop can carry in the airdrop configuration (14:79).

This table also includes the parameter for the maximum number of pallets per day the army airdrop pallet riggers can rig. The number used here was a set as one possible representative number of rigger capabilities.

The airdrop indicators were set so that only the Airborne Infantry Battalions and the 82nd Airborne Headquarters could be airdropped. The combat/combat support indicators were set so that the 82nd HQ and Artillery Battalions would be considered combat support while the Airborne Infintry Battalion, Attack Helicopter Battalion, and Mechanized Tank Battalion were considered combat. The F-16, Transportation, and ALCE were considered neither combat nor combat support as none of these units are delivered past the APOD. These indicator values were taken from Tate (28:A-6).

Requirements Data Base. The last data base table, Table XIII, is the requirements screen display.

The top of this table contains the parameters for the minimum requirements of anti-tank and front line trace capability needed in each period. The values used in this DSS are representative values, the actual values used in a study would have to be set by experts familiar with the battle scenario.

Table XIII

REQUIREMENT PARAMETERS

Name	Periods one z=1	two z=2	three z=3	four z=4
GATz	25	35	45	55
GFLTz	5	10	15	20
GCPz	Note: Combat power is the Objective so is not a goal			

L	4	Number of periods in this model, FIXED AT 4
PL	5	Period length in days used in this model

CONSUMPTION			
AT APOD AND FOL		alt r	for menu to change Requirements
START OF DEPLOYMENT		alt c	for change menu
		alt m	to return to main menu
aAPOD	200	alt p	use to print, highlight with
aFOL	100		arrow keys and press return.
a=TONC	TONS/DAY		

The number of periods is fixed at four by the mathematical formulation and to change it from four would require new constraints and variables to be added to the formulation. The period length, while set at five for this DSS, can be changed and required adjustments in the formulation would be made automatically.

The predeployment supply consumption rate parameters at the APOD and the FOL are the last of the requirements data. The values used in this DSS are representative values and the exact values would be set by examining the actual scenario under study.

Summary

This chapter has presented the first component of the DSS, the data base. The generic scenario was presented first followed by the aircraft, airfield, units, and requirements data base tables. The generic scenario shows the overall scenario that this DSS supports while the data base tables show the specific scenario developed in this presentation of the DSS. The next chapter discusses the model base component.

IV. *Model Development*

Introduction

In this chapter the linear programing model formulation is developed. Capt Cooke did the original formulation of this model. The model has evolved through the works of both Capt Tate and Maj Haile. Capt Tate updated some of the parameter names to make the model more readable, and changed some of the formulations to conform to the computer program he developed (28:ch3-1). Maj Haile applied the model using a Far Eastern scenario with one APOD (aerial port of debarkation) and one FOL (forward operating location), and he added a method of accounting for attrition in the airlift fleet (14:ix). Haile borrowed from both Cooke and Tate and again changed some of the formulations and parameters used (14:26).

Model Changes. The formulation presented in this chapter borrows heavily from Haile's formulation, changes some of the formulation, adds some new variables, and defines the parameters, some with new names to make the formulation easier to follow. Current changes to Haile's formulation are mainly in the way attrition is handled and in the way the resupply constraints are formulated.

Haile had subtracted an average combat power per aircraft from the objective function for lost missions but still allowed the aircraft loads to be delivered. The current formulation uses an additional set of attrition constraints to set the number of aircraft available for a period which is based on the number of missions flown and percentage of aircraft lost in previous periods. Also, attrited assets are subtracted from unit deliveries thus not allowing credit for lost portions of a unit and subsequently not allowing that portion of combat power to be applied.

Many changes are made in the formulation of the resupply constraints. First, previous formulations forced the model to make shipments with transportation units while the current formulation allows the linear program to use or not use the transportation units. To accomplish this a new set of variables is used to represent the number of transportation unit deliveries made to the FOL in each period. Also included in the formulation is a new set of constraints to restrict transportation unit shipments to be less than the number of transportation units availiable -- transportation units that have been delivered in previous periods. Second, the supply constraints themselves have been reformulated to make use of the new variable for truck shipments. Third, a new set of variables for aircraft payloads which consist of supplies is included in the model. Earlier formulations by Cooke and Tate included this variable but the formulation by Haile did not. Without this variable it seemed that the model used shipments of bulk cargo to satisfy constraints for both supplies and unit bulk cargo requirements. Fourth, the capabilities to account for supply consumption requirements at the APOD and FOL prior to the deployment and to fulfill those requirements during the deployment are new to the model. Previous formulations did not consider the possibility of supply requirements due to units permanently stationed at the APOD and FOL bases. This is accomplished with the new parameters TONCAPOD and TONCFOL (the tons of consumption required prior to the deployment at the APOD and FOL respectively) as the right hand side for the supply constraints.

The last two changes to the model include adding a surplus variable for rigged airdrop pallets and adding provisions for separate ground times at the APOD and FOL for each type of aircraft. The variable P(l) used for excess airdrop pallets rigged in a period was identified by Cooke. Haile used the same variable as he used for the excess unit bulk cargo shipments and it seemed there was a potential to double count cargo. The parameters GTMA(i) and GTMF(i) (ground time for aircraft i at the APOD and FOL respectively) are new. Before there was only one ground time associated with each type ofaircraft. Scheduled ground times could be different at the APOD and FOL for reasons such as aircraft refueling only at the APOD on intratheater missions.

Model Size. The current formulation uses 338 variables and 180 constraints. This is an increase of 50 variables and 12 constraints compared to Haile's formulation. The size of this formulation does tend to grow rapidly.

The variables and constraints can be grouped into period, APOD, and FOL related sets. By using the number of sets of variables and constraints in each of these groups we can create an equation to give a rough idea of how the mathematical formulation would grow with various additions.

The formulation has 86 sets of period specific variables and 44 sets of period specific constraints. For each period added onto the current formulation 86 new variables and 44 new constraints would be required. To expand from 4 periods to 30 one day periods would require,

$(26 \times 86) + 338 = 2574$ total variables

and

$(26 \times 44) + 180 = 1324$ total constraints.

The formulation has 204 variables that are concerned with delivery to the APOD of intratheater movements from the APOD. The formulation also has 44 constraints that are associated with the APOD. To add an additional APOD would require $204 + 338 = 542$ total variables and $44 + 180 = 224$ total constraints.

For the FOL the formulation has 148 variables, not counting air drop related variables, and 28 constraints. One additional FOL would require a total of $338 + 148 = 486$ variables and $180 + 28 = 208$ constraints.

Making multiple changes to the formulation does not just cause additive increases in the size requirements. For example, changing from 4 to 30 periods and from one to two APODs would not cause the number of variables to increase to 2574 + 44 = 2618. The increase from one to two APODs does at first cause the number of variables to increase by 44 but it also increases the number of period specific sets of variables from 86 to 97. When the number of periods are increased to 30 the total number of variables would increase to 338 + 44 + (26 X 97) = 2904. Similiar changes happen in the number of constraints.

Model Attributes. The model is a linear program that quantifies the value of the combat power delivered to an objective area, not in terms of tons of cargo delivered, but in terms of a time dependent value of the combat power of the military units delivered. Many factors go into the success of a large scale deployment. This model captures the effects of the following factors:

1. The three measures of combat power for military units: anti-tank, measured in TOW (tube launched optically sighted wire guided missle) equivalents; defensive frontage, measured in kilometers of front line trace capability; and firepower measured in relative firepower capabilities.
2. The type, cargo capabilities, mission capabilities, and numbers of the aircraft available for the deployment.

3. The attrition of the original aircraft as the model progresses through the four, five-day periods. The attrition rate, a percent of missions flown, can be set for individual mission and aircraft types.

4. The utilization rates of the various aircraft in the scenario.

5. The parking ramp space available at both the APOD and the FOL.

6. The material handling equipment (MHE) available at both the APOD and the FOL and the increase in capabilities that an Air Force Airlift Control Element (ALCE) provides.

7. The number of units to be deployed. In this case there are eight different unit types and various numbers of each type.

8. The different requirements of each type of unit for the four different kinds of aircraft payloads considered in this model, specifically, outsize cargo, oversize cargo, bulk cargo, and personnel. Portions of units are not considered delivered until the proper ratios of aircraft payloads have arrived.

9. The supplies required to sustain the deployed units.

10. Four different methods of delivery. The first and second are shipments of units directly to the FOL either by airland or airdrop. The third method is shipment to the APOD which either remains at the APOD

or moves to the front on its own power. Lastly, shipment to the APOD with subsequent intratheater (APOD to FOL) airlift.

11. A linkage between the combat support units and the combat units deployed and a linkage between the headquarters and the combat unit.

12. The capability of army pallet riggers to rig airdrop pallets.

The following sections of this chapter describe the development of the model. The next section starts with a listing of the variable names and definitions. Next, the parameters used in the model are provided with their names and definitions. Then, the subscripts used in this formulation along the with a definition of the values each can take on is given. The following sections describe the formulation of the objective function and the formulation of the constraints. At the end of the chapter a summary of all the equations used is presented.

Decision Variables

The first four variables presented are the same variables used in the previous formulations by Cooke, Tate, and Halle (6:46-48,14:27-29,28:ch3-1toch3-2). These variables are:

x(i,j,k,l): The number of type i aircraft loads on type j mission of type k cargo delivered in period l [ac/period] (14:27).

u(y,m,l): The number of type y units deployed by method m in period l [units/period] (14:27).

A(k,l): The excess aircraft type k payloads, at the APOD, in period l available for use against unit requirements in the next period (14:27) [tons or people].

F(k,l): The excess aircraft type k payloads, at the FOL, in period l available for use against unit requirements in the next period (14:27) [tons or people].

The following variables are new to the model:

NUM(i,l): The number of type i aircraft available in period l after considering the attrition of the previous periods [aircraft].

P(l): The excess airdrop pallets in period l, available for use against airdrop requirements in the next period [standard 462L pallets].

TRKIN(l): The number of transportation units carrying supplies from the APOD to the FOL in period l [units].

Model Parameters

This section gives the names and explanations of the parameters used throughout the model. Many of these parameters were borrowed from the previous works; although, many of the names were changed to make the equations more descriptive (6:47-50,14:29-32,28:ch3-2toch3-5).

AB(y): The airdrop indicator for unit type y, equals 1 if unit is to be airdropped at the front, 0 if airland (28:ch3-2).

AT(y): The anti-tank capability of type y unit [TOW equivalents] (28:ch3-2).

ADC(i): The airdrop capacity of type i aircraft [standard 463L pallets] (14:29).

ATRT(i,j): The attrition rate of type i aircraft flying on type j mission [% of missions flown] (14:29).

CI(y): The combat indicator of type y unit: 1 if combat unit, -1 if combat support, 0 if neither (28:ch3-2).

CARGO(i,k): The capacity of type i aircraft with type k cargo [tons/aircraft or people/aircraft] (28:ch3-3).

CPI(l): The combat power index for arriving at the front in period l (28:ch3-3).

DISUSAP: The distance between the US and the APOD [nautical miles] (28:ch3-3).

DISUSFO: The distance between the US and the FOL [nautical miles] (28:ch3-3).

DISAPFO: The distance between the APOD and the FOL [nautical miles] (28:ch3-3).

EAS(i,k): The standardization factor for the MHE required to unload type i aircraft with type k cargo [% of maximum requirement](28:ch3-3).

FLT(y): The defensive frontage, front line trace capability, of type y unit [kilometers] (28:ch3-3).

FP(y): The firepower capability of type y unit (28:ch3-3).

GAT(l): The minimum amount of anti-tank power required by period l [TOW equivalents] (28:ch3-3).

GFLT(l): The minimum amount of front line trace required by period l [kilometers] (28:ch3-3).

GTMA(i): The average scheduled ground time at the APOD for type i aircraft to offload, onload, and refuel [hours/aircraft] (28:ch3-3).

GTMF(i): The average scheduled ground time at the FOL for type i aircraft to offload, onload, and refuel [hours/aircraft].

INTER(i): The time required for type i aircraft to make a complete intertheater circuit [days] (28:ch3-3).

DISUSFO: The distance between the US and the FOL [nautical miles] (28:ch3-3).

DISAPFO: The distance between the APOD and the FOL [nautical miles] (28:ch3-3).

EAS(i,k): The standardization factor for the MHE required to unload type i aircraft with type k cargo [% of maximum requirement](28:ch3-3).

FLT(y): The defensive frontage, front line trace capability, of type y unit [kilometers] (28:ch3-3).

FP(y): The firepower capability of type y unit (28:ch3-3).

GAT(l): The minimum amount of anti-tank power required by period l [TOW equivalents] (28:ch3-3).

GFLT(l): The minimum amount of front line trace required by period l [kilometers] (28:ch3-3).

GTMA(i): The average scheduled ground time at the APOD for type i aircraft to offload, onload, and refuel [hours/aircraft] (28:ch3-3).

GTMF(i): The average scheduled ground time at the FOL for type i aircraft to offload, onload, and refuel [hours/aircraft].

INTER(i): The time required for type i aircraft to make a complete intertheater circuit [days] (28:ch3-3).

NUM(i): The number of type i aircraft dedicated to this deployment at the beginning of the first period [aircraft] (14:31).

NUMTAC: The number of fighter aircraft assigned to each deployable fighter unit [aircraft] (14:31).

PL: The period length, in this model a period is five days long [days] (14:31).

PTVL(y): The length of time it takes a type y unit to travel from the APOD to the FOL on its own power [number of periods].

RC: The army rigger capacity [pallets/day] (28:3-4)

SPD(i): The cruise speed of type i aircraft [nautical miles/hour] (28:3-4).

TON(y,k): The amount of type k cargo that must be moved for type y unit [tons or people] (28:ch3-4).

TONC(y): The supplies consumed by type y unit [tons/day] (28:ch3-4).

TMCTRK: The daily ton-mile resupply lift capability of a transportation unit [ton*miles/unit/day] (28:ch3-4).

TVL(y): The distance that unit type y can travel in one day [km/day] (28:ch3-4).

UNIT(y): The number of type y units available for this deployment (28:ch3-4).

UTE(i,j): The utilization of type i aircraft on type j mission [hrs/day] (28:ch3-4)

Index Values for this Formulation

The scenario used in this formulation require the subscripts to take on certain specific meanings. The range of each subscript and the meanings of each subscript value are:

i: a specific aircraft type, range is from 1 to I. For this model i ranges from 1 to 6 with the following aircraft:

1= C-5 Galaxy

2= C-17

3= C-141B Starlifter

4= CRAF Boeing 747 (cargo type)

5= CRAF McDonnell Douglas DC-8 (personnel type)

6= C-130/E Hercules (14:28)

j: a specific type of airlift mission, range is from 1 to J. For this model range is from 1 to 4.

1= Delivery to the APOD (intertheater)

2= Direct delivery to the front (intertheater)

3= Airdrop missions (intertheater)

4= Intratheater missions (14:28)

APOD to FOL

k: a specific cargo type range is from 1 to K. For this model k ranges from 1 to 5.

1= outsize

2= oversize

3= bulk (including supplies)

4= personnel (14:28)

5= supplies

l: a specific period, range is from 1 to 4, with each period covering five days for twenty days total (14:28)

m: the mode of delivery, range is from 1 to M. For this model m ranges from 1 to 3.

1= delivery to the front

2= delivery to the APOD and remain at the APOD or move to the front on their own

3= delivery to the APOD and move to the front via intratheater airlift (14:29)

y: a specific unit type, range is from 1 to Y, For this model range is from 1 to 8.

1= Airborne units of the 82ND Airborne Division

2= HQ units from the 82ND

3= Air Assault Units (AH-64 equipped)

4= Artillery units (155mm)

5= Mechanized Battalion (M-1s)

6= Aircraft fighter squadron (F-16s)

7= Medium truck company

8= USAF Airlift Control Element (ALCE)

All combinations of the subscripts are not possible. For example C-5 aircraft are not used for airdrop or direct delivery to the front. These restrictions are specified during the formulations of the constraints and stated implicitly in the assumptions of the scenario.

Objective Function Formulation

Combat power has three components: anti-tank capability, defensive frontage ("the capability of a unit to man a front line, or hold a perimeter...(6:13)"), and firepower. The third component, firepower, has an interesting attribute. The 1981 Congressionally Mandated Mobility Study stated that firepower delivered in a timely manner can be up to six times more effective than the same amount of firepower delivered late (5:40). This idea has become the basis for this model.

The objective function maximizes the time dependent measure of combat power, firepower delivered. The other two measures of combat power, anti-tank capability and defensive frontage are not as time critical yet they are still very important. For example without defensive frontage an F-16 squadron, which has a good amount of firepower, could not hold any ground and would be overrun. In order to keep the model from maximizing firepower, at the expense of defensive frontage and anti-tank capability, the model incorporates constraints which require minimum amounts of defensive frontage and anti-tank capability while maximizing firepower delivered. The individual requirements of defensive frontage and anti-tank capability are set for each period by experts familiar with the specific threat scenario. This is covered in further detail in the constraint formulation section.

In order to incorporate the concept of time dependence in the model a combat power index, CPI(l), is used (6:54-55). This combat power index is estimated by experts involved with the current scenario or is obtained from curves generated by simulations. This combat power index decreases over time and gives a higher value of combat power delivered to units delivered early in the deployment.

The general expression for firepower delivered to the deployment area is

$$\sum_{y=1}^{Y} \sum_{l=1}^{L'} \sum_{m=1}^{M} CPI(l)*FP(y)*u(y,m,l)$$

This equation states that a measure of firepower delivered is equal to:

[combat power index/period * fire power/unit * number of units deployed]

and is summed over all y units, all previous periods up to and including the current period L', and over all modes of delivery m.

This equation must be broken into the different modes of delivery to the deployment area because if the unit is delivered to the APOD its firepower is not available until it moves to the front on its own or is airlifted from the APOD to the FOL. When m=1 the mode of delivery is direct to the FOL, either airdrop or airland, and the firepower can be credited as soon as the unit is delivered. Under this mode of delivery the expression becomes

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'} CPI(l)*FP(y)*u(y,1,l)$$

(14:34). The only units considered to be delivered directly to the front are: y=1, 82nd Airborne; y=3, Aerial Assault; y=4, Artillery; and y=5, Mechanized.

When m=2 the unit is delivered to APOD and moves to the FOL on its own power or, if not destined for the FOL, stays at the APOD. Under this mode of delivery a unit whose destination is the FOL must not be counted as providing firepower until it actually reaches the FOL. Thus the parameter PTVL(y), the number of periods it takes a unit to reach the FOL on its own power, is included in the model. This parameter is computed as the nearest integer to:

$$DISAPFO / (TVL(Y)*PL) \quad (28:ch3-7).$$

When m=2 the objective function is

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'-PTVL} CPI(l)*FP(y)*u(y,2,l)$$

for the units that are destined for the front -- the 82nd Airborne, Airborne Assault, Artillery, and Mechanized. For the units destined to remain at the APOD the expression is

$$\sum_{y=2,6,7,8} \sum_{l=1}^{L'} CPI(l)*FP(y)*u(y,2,l)$$

These units include: the HQ82 Airborne, F-16, Transportation, and ALCE units.

When m=3 the units are moved to the APOD and subsequently moved to the FOL by intratheater airlift. The firepower is assumed to be available in less than one full period because the time to fly from the APOD to the FOL is relatively short when compared to the period length (28:ch3-7). The equation becomes

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'} CPI(l)*FP(y)*u(y,3,l)$$

Again the only units considered to be delivered to the front are: 82nd Airborne, Aerial Assault, Artillery, and Mechanized.

The completed objective function becomes

MAXIMIZE: Fire Power Capability

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'} \sum_{m=1,3} CPI(l)*FP(y)*u(y,m,l) \quad +$$

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'-PTVL(y)} CPI(l)*FP(y)*u(y,2,l) \quad +$$

$$\sum_{y=2,6,7,8} \sum_{l=1}^{L'} CPI(l)*FP(y)*u(y,2,l)$$

This objective function formulation differs from previous efforts in that both Cooke and Tate had used multiple goal programing techniques and had included all three measures of combat power in their objectives. Haile used an objective function similar to the one presented above except he included a term for combat power lost due to attrition. The formulation in the current model incorporates attrition implicitly by not crediting airlift with the delivery of cargo from attrited assets. This aspect of the model will be covered in more detail under the shipment of units constraints.

The next section begins the development of the constraints.

Constraint Formulations

As stated in the introduction section in this chapter many factors affect the capability of an airlift force to deliver combat power to a deployment area. This section will explain the logical and mathematical development of the constraints used in this mathematical programing problem.

Combat Power Constraints. There are three measures of combat power, as stated under the objective function development section. The first, fire power, was used as the variable to maximize in the objective function. The other two measures of combat power, anti-tank (AT) and defensive frontage or front line trace (FLT), will be developed as constraints requiring minimum amounts of each to be delivered or maintained in each period.

Anti-Tank Constraint. The general expression for anti-tank capability delivered to the deployment area is

$$\sum_{y=1}^{Y} \sum_{l=1}^{L'} \sum_{m=1}^{M} AT(y)*u(y,m,l)$$

This equation states that a measure of anti-tank capability delivered is equal to:

[anti-tank capability/unit * number of units deployed] and is summed over the current period and all previous periods to give a total of anti-tank capability delivered up to the end of the current period.

This equation, like the objective function, must be separated into the different modes of delivery to the deployment area for the different units. When m=1, delivery direct to the FOL either airdrop or airland, the anti-tank capability can be credited as soon as the unit is delivered. Under this mode of delivery the expression becomes

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'} AT(y)*u(y,1,l) \qquad (14:34).$$

Once again as in the objective function the only units to be delivered directly to the front are: 82nd Airborne, Aerial Assault, Artillery, and Mechanized.

When m=2, the unit is delivered to APOD and moves to the FOL on its own power or, if not destined for the FOL, stays at the APOD. As in the objective function, when this mode of delivery is used, a unit whose destination is the FOL must not be counted until it actually reaches the

FOL. Thus the parameter PTVL(y), the number of periods it takes a unit to reach the FOL on its own power must again be included. When m=2, the constraint for anti-tank capability is

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'-PTVL} AT(y)*u(y,2,l)$$

for the units that are destined for the front: the 82nd Airborne, Aerial Assault, Artillery, and Mechanized. For the units remaining at the APOD the expression is

$$\sum_{y=2,6,7,8} \sum_{l=1}^{L'} AT(y)*u(y,2,l)$$

These units include: the HQ82 Airborne, F-16, transportation, and ALCE (14:34).

When m=3, the units are moved to the APOD and subsequently moved to the FOL by intratheater airlift. The anti-tank capability is available in less than one full period because the time to fly from the APOD to the FOL is relatively short. The equation for anti-tank capability when m=3 becomes

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'} AT(y)*u(y,3,l)$$

Again the only units considered to be delivered to the front are: 82nd Airborne, Aerial Assault, Artillery, and Mechanized (14:34).

The completed constraint for anti-tank capability is

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'} \sum_{m=1,3} AT(y)*u(y,m,l) \quad +$$

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'-PTVL(y)} AT(y)*u(y,2,l) \quad +$$

$$\sum_{y=2,6,7,8} \sum_{l=1}^{L'} AT(y)*u(y,2,l) \quad \geq \quad GAT(L')$$

this equation states:

[the sum of anti-tank capability delivered, previous periods up to and including current period must be greater than or equal to the anti-tank requirement for the current period](14:35).

Defensive Frontage Constraint. The constraint development for the defensive frontage requirement is developed similar to the anti-tank requirement just covered. This equation uses the multiplier FLT(y) for the defensive frontage capability of the y type unit. The complete equation for the defensive frontage requirement is

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'} \sum_{m=1,3} FLT(y)*u(y,m,l) \quad +$$

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'-PTVL(y)} FLT(y)*u(y,2,l) \quad +$$

$$\sum_{y=2,6,7,8} \sum_{l=1}^{L'} FLT(y)*u(y,2,l) \quad \geq \quad GFLT(L')$$

this equation states:

[the sum of defensive frontage capability delivered, previous periods up to and including the current period must be greater than or equal to the defensive frontage requirement for the current period](14:35).

Aircraft Limitation Constraints. The capability to rapidly deploy troops and equipment is heavily dependent on the availability of airframes and on the number of hours per day each airframe can be expected to fly for a particular mission. This section develops three sets of constraints for sortie generation. The first set of constraints accounts for the total number of aircraft that have been dedicated to the deployment and the rate of attrition per aircraft type mission flown, and restricts the number of aircraft available in the subsequent period. The second set of constraints uses the number of different aircraft available each period. These constraints limit the number of individual sorties by using the number of days it takes a particular aircraft to fly a particular mission in this scenario. The third set of constraints in this section limits the number of sorties by looking at an overall utilization rate per aircraft and mission type. This utilization rate is the number of hours per day a particular aircraft could be expected to fly a particular mission, and is figured by "dividing the total [annual] programmed flying hours for a given aircraft type...by the primary aircraft authorized...and dividing that number by 360 to get an expected [daily] usage rate (14:43-44)." These last two sets of constraints both limit the maximum number of sorties performed by the aircraft.

Attrition Constraint. Attrition affects the deployment of troops and equipment in a number of ways.

One of the ways is by keeping certain amounts of troops and equipment from being delivered if the troops and equipment in question happen to be on an aircraft that is shot down. Another way that attrition has an effect is by reducing the number of aircraft available for use in subsequent periods.

Attrition is aircraft and mission specific. For example, certain aircraft, such as the C-141, without active defensive systems may be very susceptible to enemy attack during airdrop missions and yet be relatively safe during airland missions at the APOD. This model includes an attrition rate which is a fraction of missions flown that will be lost. These rates are determined by a detailed analysis of each aircraft and mission type. This parameter is ATRT(i,j) where i is the aircraft type and j is the type of mission; and, is related to the number of aircraft per period, NUM(i,l), by the following equation

$$\text{When } L' = 1 \qquad NUM(i,l) = NUM(i)$$

$$\text{When } L' = 2,3,4 \qquad NUM(i,l) = Num(i) - \sum_{l=1}^{L'-1} \sum_{j=1}^{J} \sum_{k=1}^{K} ATRT(i,j) * x(i,j,k,l)$$

[the number of each type of aircraft for a given period equals the number of that type in the first period, minus the sum over all previous periods of the product of the attrition rate for that aircraft and mission type and the number of that type mission flown].

Aircraft Usage Sortie Constraint. The number of sorties that the fleet of aircraft available for the deployment can produce is directly related to the time it takes the aircraft to fly a complete circuit of a particular type mission. This time would not only include the actual flight time but also the ground time required to offload, onload, refuel and do maintenance. The estimates for these times were added together to determine the total time for a particular aircraft to complete a mission and return home (or to the APOD for intratheater) ready for another mission (14:40). The two parameters INTER(i) and INTRA(i) can be thought of as aircraft days required for an aircraft type i to fly a particular mission either intertheater or intratheater. The constraint to restrict the sorties is

$$\text{INTER}(i) * \sum_{i=1,2,3,4,5} \quad \sum_{j=1}^{3} \sum_{k=1}^{K} x(i,j,k,l) \quad +$$

$$\text{INTRA}(i) * \sum_{i=2,3,6} \quad \sum_{k=1}^{K} x(i,4,k,l) \le \text{NUM}(i,l) * \text{PL}$$

[intertheater aircraft days per mission times number of intertheater missions plus intratheater aircraft days per mission times number of intratheater missions must be less than or equal to number of aircraft available times period length in days]

Utilization Rate Constraint. As defined earlier the utilization (UTE) rate is a fleet wide average hours per day of expected use per aircraft type for a specific type of mission. The surge UTE rate, used in this formulation, is a slightly higher than normal UTE rate that can be sustained for a limited period of time (usually thirty days)(14:44). The UTE rate restricts the deployment because the aircraft involved can not on the average fly more sorties than the surge UTE rate allows. Using the distance from the US to the APOD as a standard, Cooke developed a set of constraints that partitions the use of a particular type of aircraft into the four separate missions it can fly.

The basic equation that forms the foundation for the UTE rate sortie constraint is

Maximum Sorties =

(PL * UTE(i,j) * NUM(i) * SPD(i)) / (2 * DISUSAP)

[the period length times the UTE rate times the number of aircraft times the speed of the aircraft equals the total miles the aircraft can fly in a given period; divided by two (for round trip) times distance from US to APOD equals the total number of sorties available (6:58)].

UTE rates differ depending on the mission being flown and are usually higher for the long legs of the intertheater missions. Missions with higher UTE rates would generate more sorties when everything else is equal; but, when the distance between APOD and FOL (DISAPFO) is shorter than DISUSAP, the ratio

DISAPFO / DISUSAP

times the number of intratheater (APOD to FOL) missions can convert this number into an equivalant number of intertheater (US to APOD) missions. A similar ratio is used to convert missions direct to the front, both airland and airdrop, into equivalent intertheater missions. This ratio is

$$DISUSFO\ /\ DISUSAP$$

The total sorties flown must be less than or equal to an equivalent number of intertheater missions as determined by the original equation above. If total sorties flown is broken down by mission types, the ratios discussed above are used, and both sides of the equation are divided by the UTE rate then the following equation evolves

$$\sum_{i=1,2,3,4,5} \sum_{k=1}^{K} 1/UTE(i,1) * x(i,1,k,1) +$$

$$\sum_{i=2,3} \sum_{k=1}^{K} \sum_{j=2,3} 1/UTE(i,j) * \frac{DISUSFO}{DISUSAP} * x(i,j,k,1) +$$

$$\sum_{i=2,3} \sum_{k=1}^{K} 1/UTE(i,4) * \frac{DISAPFO}{DISUSAP} * x(i,4,k,1) +$$

$$\leq PL * NUM(i,1) * SPD(i) / (2 * DISUSAP)$$

(6:60,14:45). The first term above accounts for all US to APOD intertheater missions. The second term includes both airdrop and airland at the FOL, while the last term is APOD to FOL, intratheater. The second and third term apply only to C-17 and C-141. This constraint does not apply to the C-130 sorties which are strictly intratheater missions. The C-130 constraint is

$$\sum_{k=1}^{K} 1/UTE(6,4) * x(6,4,k,1)$$

$$\leq PL * NUM(6,1) * SPD(6) / (2 * DISAPFO)$$

(6:60,14:45)

Airport Facility Constraints. There are two major factors at the APOD and the FOL that can restrict the flow of aircraft. The availability of parking spaces and the capability of the material handling equipment (MHE) to offload cargo both limit the number of sorties that can transit the facility. There are four sets of constraints, two for parking and two for MHE. The parking constraint is developed first followed by the MHE constraint.

Airport Parking. Any airfield which would be considered as an APOD or FOL would be surveyed and the maximum number of each type of aircraft that can simultaneously park on the ramp would be computed. Headquarters MAC has a large data base of airfields worldwide with the maximum on the ground (MOG) listings already computed. To compute ramp saturation with different types of aircraft in the scenario a linear relationship is assumed. For example, if an airfield ramp can handle either 48 F-16s or 12 C-130s then the airfield can simultaneously hold one-half of the maximum or 24 of the F-16s and one-half of the maximum or six of the C-130s (6:61). This linear relation should hold for all but the smallest of fields where one large aircraft could block others from their parking spots (6:61).

The basic idea behind the formulation of this constraint is to break each type of sortie flown into the APOD or the FOL into the percentage of ramp that aircraft on those missions will occupy while on the ground. To do this the parameters GTMA(i) and GTMF(i), the average scheduled ground time in hours at the APOD and FOL respectively for type i aircraft, is used. The ground time is multiplied by the number of sorties to give the total amount of ground time required for a given number of missions of a certain type and aircraft. This value in turn is converted to a percentage of the total ramp space available by dividing by the total number of that type aircraft that can be parked on the ramp times the period length times 24 hours. The number of sorties has been converted to a percentage of the period-space available on the ramp (6:62).

The constraint for the APOD for each period l' is

$$\sum_{i=1}^{I} \sum_{j=1,4} \sum_{k=1}^{K} GTMA(i) * x(i,j,k,l') \,/\, (\,PL * NPRKA(i) * 24\,)$$

$$+ \sum_{l=1}^{l'} u(6,2,l') * NUMTAC \,/\, NPRKAF16 \;<=\; 1.0$$

The first term accounts for all missions through the APOD, both intertheater and intratheater and computes the percent of the ramp used per period by each type mission and aircraft. The second term reserves parking spots for any F-16 fighter unit that is delivered to the APOD and keeps those parking spots reserved throughout the deployment. When the terms on the left side of the equation equal 1 or 100% the ramp is completely saturated (6:62).

The parking constraint for the FOL is formulated the same way except that there are no fighters assigned to the FOL. The FOL parking constraint is

$$\sum_{i=2,3,6} \sum_{j=2}^{4} \sum_{k=1}^{K} GTMF(i) * x(i,j,k,l') / (PL * NPRKF(i) * 24) \leq 1.0$$

This constraint includes C-17, C-141, and C-130 aircraft flying intratheater between the APOD and the FOL, and C-17 and C-141 aircraft flying airdrop and then stopping at the FOL to refuel (14:48).

Material Handling Equipment. The material handling equipment constraints look at the number of standard pallets that each type aircraft carries on airland missions, and takes into account the capacity of the material handling equipment stationed at the APOD and the FOL.

The number of pallets that fit on each aircraft type is easy determined. The amount of material handling equipment required to unload different types of cargo is not so easily calculated (28:ch3-15). To account for the different types of cargo -- outsize, oversize, bulk, and personnel -- moved in this model the ease of offload, EAS(i,k), parameter is used. For example, if a C-17 is loaded with M-1 battle tanks (outsize), the amount of material handling equipment required would be small an EAS = .2, since the M-1 can drive off the aircraft. The same aircraft full of bulk cargo loaded on pallets would require the most material handling equipment (EAS = 1.0). The EAS values are set by experts using historical data for each aircraft and cargo type.

The quantity of material handling equipment located at both the APOD and the FOL is expressed in terms of the number of pallets per period that the equipment can handle. An ALCE unit adds additional capacity to either the APOD or FOL. Since a period is equal to five days, an ALCE is credited with an average one-half of its capacity during the period when it arrives (28:ch3-16).

The MHE constraint for the APOD for period l' is

$$\sum_{i=1}^{I} \sum_{j=1,4} \sum_{k=1}^{k} EAS(i,k) * MHE(i) * x(i,j,k,l')$$

$$- \sum_{l=1}^{l'-1} MHEALCE * PL * u(8,2,l)$$

$$- .5 * MHEALCE * PL * u(8,2,l') \leq MHEAPOD * PL$$

The constraint for the FOL for period l' is

$$\sum_{i=2,3,6} \sum_{j=2,4} \sum_{k=1}^{k} EAS(i,k) * MHE(i) * x(i,j,k,l')$$

$$- \sum_{l=1}^{l'-1} \sum_{m=1,3} MHEALCE * PL * u(8,m,l)$$

$$- \sum_{m=1,3} .5 * MHEALCE * PL * u(8,m,l') \leq MHEFOL * PL$$

Both sets of constraints restrict the sorties through the

APOD and the FOL to be no greater than the requirements to upload or download the aircraft minus the capabilities of ALCE units previously delivered and half of the capability of ALCE units delivered this period and must all be less than the capabilities of the material handling equipment stationed there (6:64). Both account for intertheater and intratheater missions while the FOL constraint does not include a requirement for offloading airdrop missions which stop at the FOL for refuel only.

Unit Limitation Constraints. The unit limitation constraints refer to the eight types of units to be delivered during the deployment. The first set of constraints restricts the number of units deployed to the number available for the deployment. The second set requires that all the four types of cargo required by a unit be delivered in the proper ratios before any portion of that units combat power can be applied. The last set of constraints in this section deals with unit linkage, or requiring certain types of units, like combat support and headquarters to be deployed along with the combat units.

Unit Limitation. This set of constraints restricts the number of units deployed to be less than or equal to the number available for the deployment (6:64). The constraint for unit limitation for each type unit y is

$$\sum_{m=1}^{3} \sum_{l=1}^{L} u(y,m,l) \quad <= \quad UNIT(y)$$

[the sum of all different modes of delivery, m, over all

the periods, l, of each unit type, y, is less than or equal to the number of units available]
(6:64,14:50,28:ch3-17).

Shipment Of Units. A unit consist of its personnel and the outsize, oversize, and bulk tonnage that belongs to it. These are cargo types k equal one to four. When the proper mix of cargo type components of a unit have been delivered then that percentage of the unit is considered delivered and its combat power is counted. In this model units are initially shipped either to the APOD, direct to the front, or airdropped at the front. The following constraints look at either the tons of each type of cargo delivered or number of personnel by each method of delivery and allocates these numbers to the requirements of the units delivered. Excess tonnage delivered in a period becomes the variables A(k,l) and F(k,l) which are excess type k payloads, at the APOD and FOL respectively, available for use against unit requirements in the next period. Initial excess tonnage, F(k,0) and A(k,0) are assumed to be zero in all cases.

Attrition was not previously considered in this part of the model and this allowed units to be credited with delivery of all cargo shipped even if aircraft were lost. Attrition is modeled by subtracting one-half the attrition rate times the cargo times the number of missions. The one-half is because the aircraft is just as likely to be lost on its way out when it is empty as on its way in when it is full.

The constraint for the delivery of units in period l' for each type cargo k, k not equal to 5 (supplies), to the APOD is

$$\sum_{i=1}^{5} CARGO(i,k) * x(i,1,k,l')$$

$$- \sum_{i=1}^{5} .5 * ATRT(i,1) * CARGO(i,k) * x(i,1,k,l')$$

$$- \sum_{y=1}^{Y} \sum_{m=2} TON(y,k) * u(y,m,l')$$

$$- \sum_{y=1,3,4,5,8} \sum_{m=3} TON(y,k) * u(y,m,l')$$

$$+ A(k,l'-1) - A(k,l') = 0$$

[the total tonnage of each type k cargo, k not equal to 5, on all missions to the APOD, minus attrited cargo, minus the tonnage required of type k cargo of all units delivered to the APOD, m=2, or Delivered to the APOD and moved with intratheater airlift, m=3, plus excess type k cargo from last period minus excess type k cargo this period equals zero] (6:64,14:50,28:ch3-17).
This constraint essentially sets the value of the excess, A(k,l), for this period. In this constraint when y equals 2, 6,or 7, m cannot equal 3 because the Headquarters, F-16 and truck units remain at the APOD and do not move to the FOL.

An additional constraint is needed to insure that cargo delivered to the APOD and requiring intratheater airlift to the FOL is actually moved to the FOL. This constraint shows that not all units are destined for the FOL. This constraint for cargo type k, k not equal to 5, in period 1' is:

$$\sum_{i=2,3,6} CARGO(i,k) * x(i,4,k,1')$$

$$- \sum_{i=2,3,6} .5 * ATRT(i,4) * CARGO(i,k) * x(i,4,k,1')$$

$$- \sum_{y=1,3,4,5,8} TON(y,k) * u(y,3,1')$$

$$+ F(k,1'-1) - F(k,1') = 0$$

[the sum of the type k cargo, k not equal to 5, on the C-17s, C-141s, and C-130s flying intratheater missions, minus the attrited cargo, minus the requirements for type k cargo of the 82nd Airborne, Air Assault, Artillery, Mechanized and ALCE units plus excess type k delivered last period minus excess this period equals zero] (14:51,28:ch3-18)

The direct delivery of units to the FOL is considered next. This constraint is similar to the constraint for delivery to the APOD except that only the C-17 and C-141 are capable of direct delivery to the FOL. The indicator AB(y) is used in this constraint to distinguish between units that can be airdropped and those that must be airlanded at the FOL. AB(y) equals one for units to be airdropped and zero otherwise. The formulations of this constraint by Tate included a (1-AB(y)) term. By including the (1-AB(y)) in this constraint units that are to be airdropped when directly delivered to the front will not count against the cargo directly delivered by airland.

The constraint for type k , k not equal to 5, cargo in period 1' is

$$\sum_{i=2,3} CARGO(i,k) * x(i,2,k,1')$$

$$- \sum_{i=2,3} .5 * ATRT(I,2) * CARGO(i,k) * x(i,2,k,1')$$

$$- \sum_{y=1,3,4,5,8} (1-AB(y)) * TON(y,k) * u(y,1,1')$$

$$+ F(k,1'-1) - F(k,1') = 0$$

[the sum of cargo type k, k not equal to 5, on C-17 and C-141 direct to the FOL airland missions, minus the attrited cargo, minus the requirements of the units to be direct delivered by airland to the FOL plus excess from last period at the FOL minus excess this period equals zero](6:66,14:51,28:ch3-18)

The last method of delivery is direct delivery to the FOL by airdrop. The only two aircraft in this model capable of intertheater airdrop are the C-17 and the C-141. The indicator AB(y) as discussed in the last constraint is again used to match airdropped units with their cargo requirements. This constraint for cargo k , k not equal to 5, in period 1' is

$$\sum_{i=2,3} CARGO(i,k) * x(i,3,k,1')$$

$$- \sum_{i=2,3} .5 * ATRT(i,3) * CARGO(i,k) * x(i,3,k,1')$$

$$- \sum_{y=1,3,4,5,8} AB(y) * TON(y,k) * u(y,1,1')$$

$$+ F(k,1'-1) - F(k,1') = 0$$

[the sum of cargo type k, k not equal to 5, on C-17 and C-141 direct to the FOL airdrop missions, minus the attrited cargo, minus the requirements of the units to be direct delivered by airdrop to the FOL plus excess from last period at the FOL minus excess this period equals zero](6:66,14:52,28:ch3-19)

Unit Linkage. The following constraints create a linkage between the different type of units -- combat, combat support, and headquarters -- deployed in this model. This set of constraints sets floors and ceilings for different types of units deployed. A floor would be requiring a certain type of unit to be deployed given that other units are already deployed (6:72); for example, requiring one headquarters unit be deployed for every three to five combat units deployed. A ceiling would be requiring other types of units to be deployed prior to the deployment of a certain unit; for example, before a combat support unit can be deployed a combat unit must be deployed to protect it (6:71).

This model uses a unit linkage between the 82nd Airborne and the 82nd Headquarters as a floor constraint. The ratio desired is at least one headquarters per five Airborne battalions, although this ratio is flexible. In order to allow at least two battalions to be delivered before the first headquarters unit but to require a second headquarters before the sixth battalion is delivered, a third before the ninth, and so on the following constraint for units delivered is used

$$\sum_{m=1}^{3} \sum_{l=1}^{L} u(1,m,l) - 3 * \sum_{l=1}^{L} u(2,2,l) <= 2$$

[the number of airborne units delivered to the theater minus three times the number of headquarters units (delivered only to the APOD) must be less than or equal to two](6:72,14:58,28:ch3-25).

The requirement to have at least as many combat units as combat support is also modeled. The combat indicator CI(y) is used and indicates +1 if a unit is a combat unit, -1 if a unit is combat support, and 0 if neither such as an ALCE unit. This constraint for units delivered is

$$\sum_{y=1}^{Y} \sum_{m=1}^{3} \sum_{l=1}^{L} CI(y) * u(y,m,l) >= 0$$

[the sum of all the units deployed times their respective combat indicator should be greater than or equal to zero] (6:71,14:58,28:ch3-24).

Resupply Constraints. The model would not be complete if it did not include the resupply of the units delivered to the objective area and the resupply of the units stationed there at the start of the deployment. A special category k=5 is used in this model to represent supplies needed by the units. While resupply [illegible] be those with k=5, the capabilities of the [illegible] carry supplies are the same as to carry [illegible] the capacities to carry bulk is [illegible] supplies.

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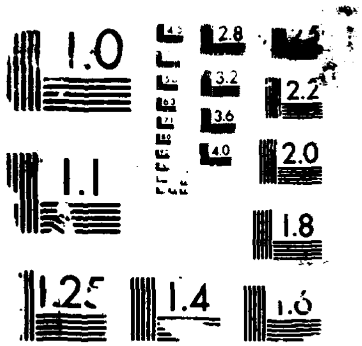


MICROCOPY RESOLUTION TEST CHART

The formulation of the supply constraints in this model are somewhat different from previous formulations. There is a set of constraints for the APOD and a set for the FOL. The amount of supplies coming into the APOD or FOL (including previous period excess) minus all the demands on supplies at that APOD or FOL (including supplies left for next period) must equal zero. The constraints for the supplies carried by truck units will be discussed first followed by the development of the actual APOD and FOL supply constraints.

Truck Capacity. The only units deployed in this model that possess any lift capability are the transportation units delivered to the APOD during the various periods. These truck units have a capacity to haul a fixed number of tons of cargo a fixed number of miles in a day which is given by the parameter TMCTRK. To determine the number of tons of supplies that a truck unit can carry from the APOD to the FOL in a period the distance from the APOD to the FOL, DISAPFO, and period length, PL, must be used in the following equation

TMCTRK * PL / (2 * DISAPFO)

[((Ton miles/day) * (days/period)) / (round trip miles)] (6:68,14:54, 28:ch3-21). This is the number of tons of supplies that each truck unit deployed can deliver to the FOL in a period and will be used as the multiplier for the variable TRKIN(1), the number of truck unit shipments in period 1. The parameter PTVL(y) is computed for each unit that can move to the front on their own including the truck unit and equals DISAPFO/(PL*TVL(Y)) the distance between the APOD and FOL divided by the number of days in a period times the distance unit y can travel in a day and is the number of periods that it takes unit y to reach the front. The variable TRKIN(i) is new to model and is restricted to keep truck unit shipments less than the number of truck units previously deployed. The constraint for period l' is

$$TRKIN(l') - \sum_{l=1}^{l'-PTVL(7)} u(7,2,l) \quad <= \quad 0$$

[the number of truck unit shipments in a period minus the number of truck units deployed in previous periods must be less than or equal to zero]. The TRKIN(l) variable is used in the APOD and FOL supply constraints.

Supplies at the APOD. As stated earlier the supply constraint at the APOD will be the supplies brought into the APOD plus excess supplies last period minus demands this period and excess this period. The demands on supplies this period come from all units that were delivered in previous periods. Storage for supplies is considered to be unlimited although the model gains nothing for delivery of an excessively large amount of supplies above the quantity needed. The units delivered in the current period are assumed to have enough supplies with them to last one period. Units that travel to the FOL on their own and take longer than one period to reach the FOL will continue to demand supplies at the APOD until they reach the FOL. The right hand side of this constraint will be the demand for supplies that existed at the APOD prior to the deployment and continues through the deployment period. The constraint for supplies, k=5, at the APOD for period l' is

$$\sum_{i=1}^{5} CARGO(i,3) * x(i,1,5,l') + A(5,l'-1)$$

$$- \sum_{i=2,3,6} CARGO(i,3) * x(i,4,5,l')$$

$$- TMCTRK * PL/(2 * DISAPFO) * TRKIN(l')$$

$$- \sum_{l=1}^{l'-1} \sum_{y=2,6,7,8} TONC(y) * u(y,2,l)$$

$$- \sum_{l=1}^{PTVL(y)-1} \sum_{y=1,3,4,5} TONC(y) * u(y,2,l)$$

$$- A(5,l')$$

$$= TONCAPOD$$

[The tons of supplies delivered by all aircraft flying intertheater missions to the APOD, plus the tons of supplies left after the last period, minus the tons of supplies moved by C-17s, C-141s, and C-130s on intratheater missions to the FOL, minus the tons carried by truck units overland to the FOL, minus tons of supplies required by all units delivered to and remaining at the APOD in all previous periods, minus tons of supplies required by units delivered to the APOD and enroute to the FOL on their own and traveling longer than one period, minus excess this period equals the tons of supplies required for units that have been stationed at the APOD since the start of the deployment]. This constraint essentially sets the excess value from the current period to be used in the next period.

FOL Supplies. Supply requirements at the FOL are figured the same way as at the APOD. The supplies brought into the FOL plus excess supplies from the last period minus demands this period and excess this period equals the demand of the units stationed at the FOL at the beginning of the deployment. The demands on supplies this period come from all units that were delivered in previous periods. The units delivered in the current period are assumed to have enough supplies with them to last one period. The constraint for supplies at the FOL in period l' is

$$
\begin{aligned}
&\sum_{i=2,3}\ \sum_{j=2,3} CARGO(i,3) * x(i,j,5,l') + F(5,l'-1) \\
&\quad + \sum_{i=2,3,6} CARGO(i,3) * x(i,4,5,l') \\
&\qquad + TMCTRK * PL/(2 * DISAPFO) * TRKIN(l'-PTVL(7)) \\
&\qquad\quad - \sum_{l=1}^{l'-1}\ \sum_{y=1,3,4,5}\ \sum_{m=2}^{3} TONC(y) * u(y,m,l) \\
&\qquad\quad - \sum_{1+PTVL(y)}^{l'}\ \sum_{y=1,3,4,5} TONC(y) * u(y,2,l) \\
&\qquad\qquad - F(5,l') \\
&\qquad\qquad\quad = TONCFOL
\end{aligned}
$$

[the tons of supplies delivered by C-17s and C-141s direct by airdrop and airland to the FOL, plus the supplies left over from last period, plus supplies arriving by intratheater airlift on C-17s, C-141s, and C-130s, plus cargo arriving by truck, minus the tons of supplies required by all units delivered in previous periods by direct delivery and intratheater, minus supplies required by all units that have arrived on their own in previous periods at the FOL, minus the excess supplies this period at the FOL equals the tons of supplies consumed by the units stationed at the FOL prior to and remaining through the deployment].

Airdrop Pallet Constraints. This constraint restricts the number of resupply airdrop sorties by limiting them to the number of pallets that Army riggers can configure in a period. This constraint requires a slack variable P(l) which is the excess supply pallets rigged for airdrop but not used in period l. The constraint for supply pallets rigged in period l' is

$$\sum_{i=2,3} ADC(i) * x(i,3,5,l') - P(l'-1) + P(l') = RC * PL$$

[The number of pallets on the C-17s and C-141s during airdrop of supplies, minus the excess pallets rigged for airdrop last period plus the excess pallets rigged this period equals the rigger capacity per day times the period length in days](6:73). This constraint sets the excess each period to be used in the next period.

Summary Of Formulation

The mathematical formulation of this model has been adapted from the works of Captains Cooke and Tate and Major Haile. The changes have been noted in this chapter. This chapter concludes with a listing of the objective and constraint equations of the model and the number of each required for the model.

--Objective Function Formulation

MAXIMIZE: Fire Power Capability (one for model)

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'} \sum_{m=1,3} CPI(l)*FP(y)*u(y,m,l) \quad +$$

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'-PTVL(y)} CPI(l)*FP(y)*u(y,2,l) \quad +$$

$$\sum_{y=2,6,7,8} \sum_{l=1}^{L'} CPI(l)*FP(y)*u(y,2,l)$$

--Constraint Formulations

---Combat Power Constraints

----Anti-Tank Constraint
(one for each period 1, 4)

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'} \sum_{m=1,3} AT(y)*u(y,m,l) \quad +$$

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'-PTVL(y)} AT(y)*u(y,2,l) \quad +$$

$$\sum_{y=2,6,7,8} \sum_{l=1}^{L'} AT(y)*u(y,2,l)$$

$$\geq GAT(L')$$

----Defensive Frontage Constraint
(one for each period 1, 4)

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'} \sum_{m=1,3} FLT(y)*u(y,m,l) \quad +$$

$$\sum_{y=1,3,4,5} \sum_{l=1}^{L'-PTVL(y)} FLT(y)*u(y,2,l) \quad +$$

$$\sum_{y=2,6,7,8} \sum_{l=1}^{L'} FLT(y)*u(y,2,l)$$

$$\geq \; GFLT(L')$$

---Aircraft Limitation Constraints

----Attrition Constraint (one for period and aircraft type for (L-1) * I = 18 constraints)

When l'=1 $\qquad NUM(i,l) = NUM(i)$

When l'=2,3,4 $\quad NUM(i,l) + \sum_{l=1}^{l'-1} \sum_{j=1}^{J} \sum_{k=1}^{K} ATRT(i,j) * x(i,j,k,l)$

$$= Num(i)$$

----Aircraft Usage Sortie Constraint (one for period and aircraft type for L * I = 24 constraints)

$$INTER(i) * \sum_{i=1,2,3,4,5} \sum_{j=1}^{3} \sum_{k=1}^{K} x(i,j,k,l) \quad +$$

$$INTRA(i) * \sum_{i=2,3,6} \sum_{k=1}^{K} x(i,4,k,l) - NUM(i,l) * PL \leq 0$$

----Utilization Rate Constraint (one for period and aircraft type for L * I = 24 constraints)

$$\sum_{i=1,2,3,4,5} \sum_{k=1}^{K} 1/UTE(i,1) * x(i,1,k,l) +$$

$$\sum_{i=2,3} \sum_{k=1}^{K} \sum_{j=2,3} 1/UTE(i,j) * \frac{DISUSFO}{DISUSAP} * x(i,j,k,l) +$$

$$\sum_{i=2,3} \sum_{k=1}^{K} 1/UTE(i,4) * \frac{DISAPFO}{DISUSAP} * x(i,4,k,l) +$$

$$- PL * NUM(i,l) * SPD(i) / (2 * DISUSAP) \leq 0$$

-----The C-130 constraint is:

$$\sum_{k=1}^{K} 1/UTE(6,4) * x(6,4,k,l)$$

$$- PL * NUM(6,l) * SPD(6) / (2 * DISAPFO) \leq 0$$

---Airport Facility Constraints

----Airport Parking (one per period or 2*4=8 constraints)

-----The APOD constraint for each period l' is:

$$\sum_{i=1}^{I} \sum_{j=1,4} \sum_{k=1}^{K} GTM(i) * x(i,j,k,l') / (PL * NPRKA(i) * 24)$$

$$+ \sum_{l=1}^{l'} u(6,2,l') * NUMTAC / (NPRKAF-16 * PL) <= 1.0$$

-----The FOL parking constraint is:

$$\sum_{i=2,3,6} \sum_{j=2}^{4} \sum_{k=1}^{K} GTM(i) * x(i,j,k,l') / (PL * NPRKF(i) * 24)$$

$$<= 1.0$$

----Material Handling Equipment (one per period or 2*4=8 constraints)

-----The constraint for the APOD for period l' is:

$$\sum_{i=1}^{I} \sum_{j=1,4} \sum_{k=1}^{k} EAS(i,k) * MHE(i) * x(i,j,k,l')$$

$$- \sum_{l=1}^{l'-1} MHEALCE * PL * u(8,2,l)$$

$$- .5 * MHEALCE * PL * U(8,2,l') \le MHEAPOD * PL$$

-----The constraint for the FOL for period l' is:

$$\sum_{i=2,3,6} \sum_{j=2,4} \sum_{k=1}^{k} EAS(i,k) * MHE(i) * x(i,j,k,l')$$

$$- \sum_{l=1}^{l'-1} \sum_{m=1,3} MHEALCE * PL * u(8,m,l)$$

$$- \sum_{m=1,3} .5 * MHEALCE * PL * U(8,m,l') \le MHEFOL * PL$$

---Unit Limitation Constraints

----Unit Limitation (one per unit y = 8)

$$\sum_{m=1}^{3} \sum_{l=1}^{L} u(y,m,l) <= UNIT(y)$$

----Shipment Of Units

-----To the APOD (two per unit cargo type and period or 2*4*4=32)

$$\sum_{i=1}^{5} CARGO(i,k) * x(i,1,k,l')$$

$$- \sum_{i=1}^{5} .5 * ATRT(i,1) * CARGO(i,k) * x(i,1,k,l')$$

$$- \sum_{y=1}^{Y} \sum_{m=2}^{3} TON(y,k) * u(y,m,l')$$

$$+ A(k,l'-1) - A(k,l') = 0$$

$$\sum_{i=2,3,6} CARGO(i,k) * x(i,4,k,l')$$

$$- \sum_{i=2,3,6} .5 * ATRT(i,4) * CARGO(i,k) * x(i,4,k,l')$$

$$- \sum_{y=1,3,4,5,8} TON(y,k) * u(y,3,l')$$

$$+ F(k,l'-1) - F(k,l') = 0$$

-----To the FOL (two per unit cargo type and period or 2*4*4=32)

$$\sum_{i=2,3} CARGO(i,k) * x(i,2,k,l')$$

$$- \sum_{i=2,3} .5 * ATRT(I,2) * CARGO(i,k) * x(i,2,k,l')$$

$$- \sum_{y=1,3,4,5,8} (1-AB(y)) * TON(y,k) * u(y,1,l')$$

$$+ F(k,l'-1) - F(k,l') = 0$$

$$\sum_{i=2,3} CARGO(i,k) * x(i,3,k,l')$$

$$- \sum_{i=2,3} .5 * ATRT(i,3) * CARGO(i,k) * x(i,3,k,l')$$

$$- \sum_{y=1,3,4,5,8} AB(y) * TON(y,k) * u(y,1,l')$$

$$+ F(k,l'-1) - F(k,l') = 0$$

----Unit Linkage

-----Headquarters (one per model)

$$\sum_{m=1}^{3} \sum_{l=1}^{L} u(1,m,l) - 3 * \sum_{l=1}^{L} u(2,2,l) <= 2$$

-----Combat Support (one per model)

$$\sum_{y=1}^{Y} \sum_{m=1}^{3} \sum_{l=1}^{L} CI(y) * u(y,m,l) >= 0$$

---Resupply Constraints

----Truck Capacity. (one per period or 4)

$$TRKIN(l') - \sum_{l=1}^{l'-PTVL(7)} u(7,2,l) <= 0$$

----Supplies at the APOD (one per period or 4)

$$\sum_{i=1}^{5} CARGO(i,3) * x(i,1,5,l') + A(5,l'-1)$$

$$- \sum_{i=2,3,6} CARGO(i,3) * x(i,4,5,l')$$

$$- TMCTRK * PL/(2 * DISAPFO) * TRKIN(l')$$

$$- \sum_{l=1}^{l'-1} \sum_{y=2,6,7,8} TONC(y) * u(y,2,l)$$

$$- \sum_{l=1}^{PTVL(y)-1} \sum_{y=1,3,4,5} TONC(y) * u(y,2,l)$$

$$- A(5,l')$$

$$= TONCAPOD$$

----FOL Supplies (one per period or 4)

$$\sum_{i=2,3} \sum_{j=2,3} CARGO(i,3) * x(i,j,5,l') + F(5,l'-1)$$

$$+ \sum_{i=2,3,6} CARGO(i,3) * x(i,4,5,l')$$

$$+ TMCTRK * PL/(2 * DISAPFO) * TRKIN(l'-PTVL(7))$$

$$- \sum_{l=1}^{l'-1} \sum_{y=1,3,4,5} \sum_{m=2}^{3} TONC(y) * u(y,m,l)$$

$$- \sum_{l+PTVL(y)}^{l'} \sum_{y=1,3,4,5} TONC(y) * u(y,2,l)$$

$$- F(5,l')$$

$$= TONCFOL$$

----Airdrop Pallet Constraints (one per period or 4)

$$\sum_{i=2,3} ADC(i) * x(i,3,5,l') - P(l'-1) + P(l') = RC * PL$$

Summary

This chapter has presented the complete model base of this DSS. The third component of the DSS, the man-machine interface is discussed in the next chapter.

V. Man-Machine Interface

Introduction

This chapter contains the third and final component of this DSS, the man-machine interface. This component of the DSS is the component that facilitates the user friendliness of the DSS. As was discussed in chapter II a characteristic of any DSS is that it is interactive and user friendly. This DSS, which uses microcomputer CRT and keyboard for inputs and CRT, disk drive, or printer for outputs, is interactive. This chapter presents the man-machine interface of this DSS by first describing two feature charts, which are basically wiring diagrams showing the menus used in this DSS. A description of the Hookbook and Notepad are included in the feature chart section. Next, the menus are presented along with the built-in help function. Lastly a brief description of the input screen displays and a description of the output screen displays for the kernel problem identified in chapter II is given.

Feature Charts

This section contains two feature charts of this DSS. Figure 2 is the feature chart for the input spreadsheet and Figure 3 is the feature chart for the output spreadsheet.

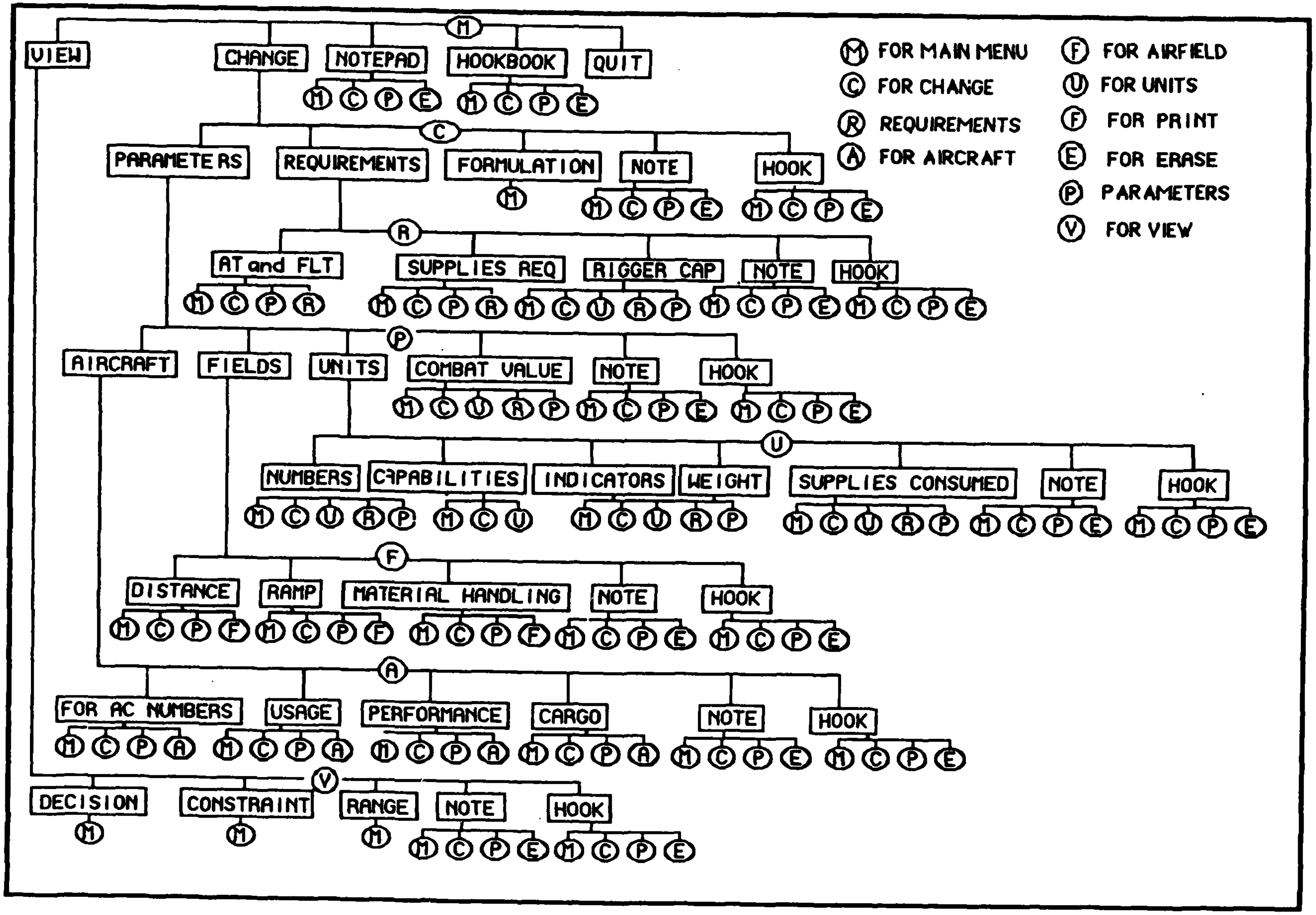


Figure 2. Input Feature Chart

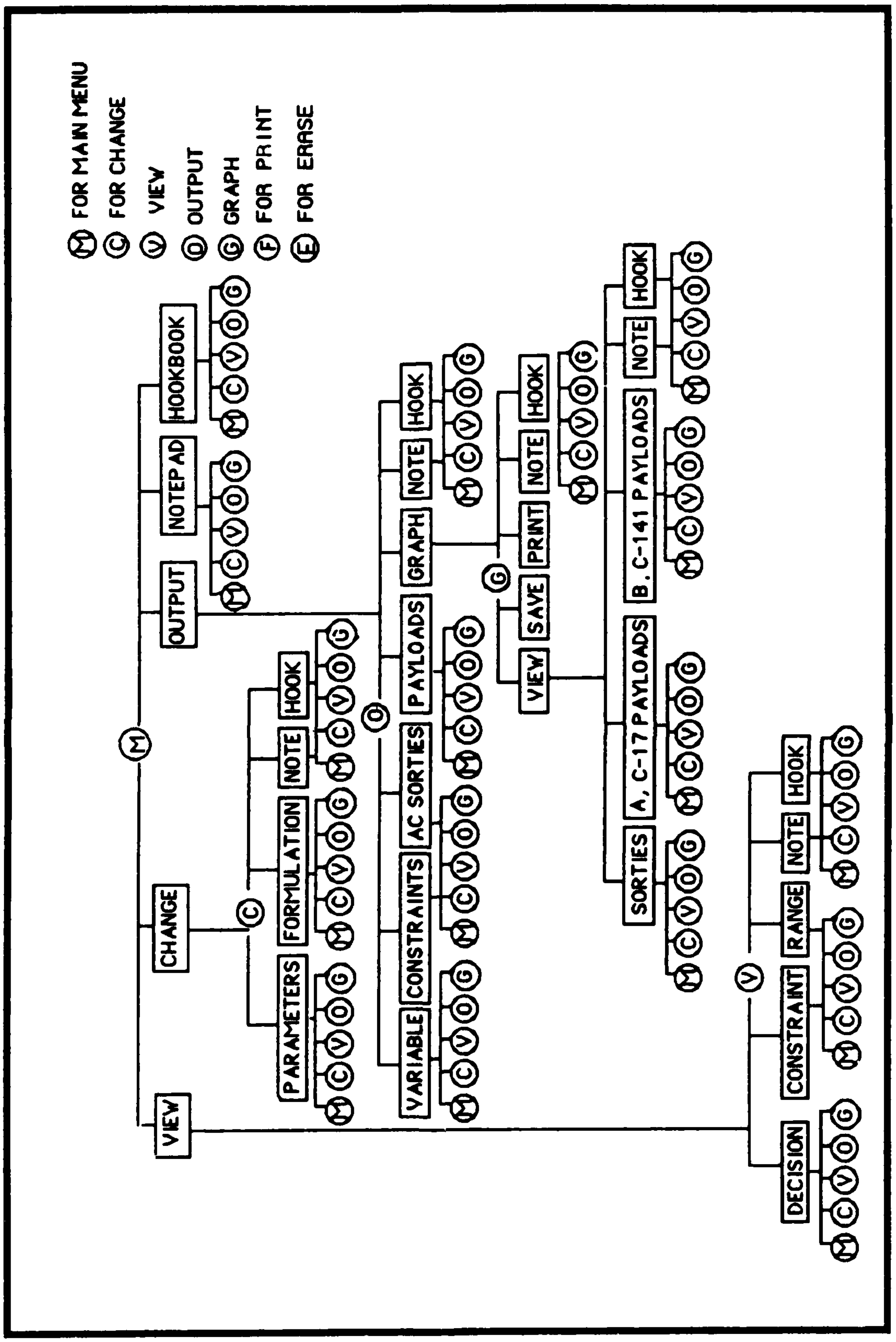


Figure 3. Output Feature Chart

The feature chart is designed to show the user the relationships of the various menus available. The feature chart incorporates the ROMC design approach as discussed in chapter II and can be used to show the representations, operations, memory aids and control mechanisms of the DSS (24:11-13).

These feature charts contain the wiring diagram for the menus used in this DSS. These menus basically lead the user to the screen displays to view and change the data-bases on the input side, and take the user to the screen displays for the output side. Each row on the feature chart represents a menu, each boxed item is a menu selection, and the lowest box in each hierarchy takes the user to a screen display. The circled letters at the bottom of each selection represents either the menus that the DSS allows you to easily access from that screen display or the utilities of printing and erasing.

Hookbook and Notepad. As stressed in chapter II two important parts of the DSS are included on every menu. They are the hookbook, for the user to leave notes for the system designer and builder, and the notepad, for the user to leave notes to himself. These two screen displays are presented in Figures 4 and 5. These capabilities of this DSS are not only user friendly but also help the user keep track of changes identified for the DSS. This feature supports the adaptability required in a DSS.

HOOKBOOK	Use this area to enter, review, delete or print notes to the system designer. As you type the message will apear above the spreadsheet, use down arrow when at the end of a line. Include a date, a label, the idea, and the circumstances.
alt p	use to print, highlight with arrow keys press return.
alt e	use to erase, highlight with arrow keys press return.
alt c	to return to change menu
alt m	to return to main menu
Esc	use Escape key if error is made when highlighting.
notes:	*** reminder ***: date, label, idea, circumstances

Figure 4. Hookbook Display

NOTEPAD	Use this area to enter, review, delete or print notes to yourself. As you type notes they will appear above the spreadsheet, use down arrow key when you are at the end of a line.
alt p	use to print, highlight with arrow keys press return.
alt e	use to erase, highlight with arrow keys press return.
alt c	to return to change menu
alt m	to return to main menu
Esc	use Escape key if error is made when highlighting.
notes:	

Figure 5. Notepad Display

These screen displays have the same purpose in mind. Both of these areas in the DSS are designed for the user to leave messages. The difference is that in the case of the first display the user leaves messages to himself and in the case of the second the user leaves messages to the system designer or builder.

The basic idea on these two screens is to instruct the user how to leave messages and to give him the memory aids necessary to return to the menu desired. The "alt x" areas are highlighted in green to draw attention to them as memory and training aids. Also, on the hookbook screen the instructions to include the date, label, idea, and circumstances are highlighted in green to get the user to follow a format that will facilitate communication at a later date of the ideas entered in this area.

Menus

This section gives the menus and the descriptions of each menu item. It begins with the screen display the user initially sees when calling up the input spreadsheet. Then the input and output menus are presented.

Initial Screen. Figure 6 is the initial screen display and main menu which appear when the user calls up the input spreadsheet.

```
VIEW     CHANGE   NOTEPAD  HOOKBOOK   QUIT
Use to Look at Decision, Constraint, or Range Names


ACAR, A COMBAT POWER DELIVERED DECISION SUPPORT SYSTEM

Use the menus provided above the spreadsheet to move through the
different tables and the formulation.

Use the arrow keys to move within the tables.
To change a number in a table put cursor on proper
cell, type new value and return.

When done with changes in a table select appropriate menu,     alt x
by holding down [alt] key and pressing appropriate letter.
```

Figure 6. Initial Screen Display

This first objective of this screen display is to tell the user the title of the DSS. This representation shows the title in green so that the title stands out. Following the tittle are some instructions meant to function as training and memory aids to help the user control this DSS. The main menu appears at the top of the display to allow the user to get started on the operations of the DSS. Any menu item can be selected by either just selecting the first letter of that menu item or by using the arrow key to highlight the item and then pressing return.

An important memory aid and training aid is the explanation of the menu item the user has highlighted. This explanation appears on the second line of the display under the menu. The two ways of selecting menu items allows the user to use the help explanations if needed or bypass them if already familiar with the menus.

Input Menus. The development of menus to lead the user through the data bases and the output of the linear program model requires the user to know very little about the software used for this DSS. The menus for the input spreadsheet are shown in Figure 7 through Figure 14. The purpose of these figures is to show the help explanations that can be displayed with each menu. Each two lines in these figures correspond to the menu and the explanation of the menu item selected (boxed). These are the displays the user sees at the top of the spreadsheet.

VIEW CHANGE NOTEPAD HOOKBOOK QUIT
Use to Look at Decision, Constraint, or Range Names

VIEW CHANGE NOTEPAD HOOKBOOK QUIT
Use to Change Parameters, Right-Hand Sides, or Formulation

VIEW CHANGE NOTEPAD HOOKBOOK QUIT
Move to the notepad where notes can be entered, reviewed, printed or deleted.

VIEW CHANGE NOTEPAD HOOKBOOK QUIT
A place to leave notes on system design and improvement for the manager.

VIEW CHANGE NOTEPAD HOOKBOOK QUIT
Quit the DSS Menu and Return to Lotus 123

Figure 7. Input Main Menu

PARAMETERS REQUIREMENTS FORMULATION NOTEPAD HOOKBOOK
Allows Selection of Different Tables of Parameters for Editing

PARAMETERS REQUIREMENTS FORMULATION NOTEPAD HOOKBOOK
To Select and Change Tables of AT and FLT, Predeployment Supply and Rigger Cap.

PARAMETERS REQUIREMENTS FORMULATION NOTEPAD HOOKBOOK
Places You at the Constraint Matrix for Manually Reworking Formulations

PARAMETERS REQUIREMENTS FORMULATION NOTEPAD HOOKBOOK
Move to the notepad where notes can be entered, reviewed, printed or deleted.

PARAMETERS REQUIREMENTS FORMULATION NOTEPAD HOOKBOOK
A place to leave notes on system design and improvement for the manager.

Figure 8. Input Change Menu

AT and FLT SUPPLIES REQ RIGGER CAP NOTEPAD HOOKBOOK
Use to set Min Requirements for Anti-Tank and Defensive Frontage per Period

AT and FLT SUPPLIES REQ RIGGER CAP NOTEPAD HOOKBOOK
Use to set Tons of Daily Supply Reqd at APOD and FOL Due to Permanent Units

AT and FLT SUPPLIES REQ RIGGER CAP NOTEPAD HOOKBOOK
Use to set Army Airdrop Rigger Capacity

AT and FLT SUPPLIES REQ RIGGER CAP NOTEPAD HOOKBOOK
Move to the notepad where notes can be entered, reviewed, printed or deleted.

AT and FLT SUPPLIES REQ RIGGER CAP NOTEPAD HOOKBOOK
A place to leave notes on system design and improvement for the manager.

Figure 9. Input Requirements Change Menu

```
AIRCRAFT  FIELDS   UNITS    COMBAT VALUE  NOTEPAD  HOOKBOOK
Use this to Change Aircraft Numbers and Capabilities

AIRCRAFT  FIELDS   UNITS    COMBAT VALUE  NOTEPAD  HOOKBOOK
Use this to Change APOD and FOL Parking and MHE Capabilities

AIRCRAFT  FIELDS   UNITS    COMBAT VALUE  NOTEPAD  HOOKBOOK
Use this to Change Weights, Capabilities, and Indicators of Units to Deploy

AIRCRAFT  FIELDS   UNITS    COMBAT VALUE  NOTEPAD  HOOKBOOK
Use this to Change the Combat Value Over Time Multipliers

AIRCRAFT  FIELDS   UNITS    COMBAT VALUE  NOTEPAD  HOOKBOOK
Move to the notepad where notes can be entered, reviewed, printed or deleted.

AIRCRAFT  FIELDS   UNITS    COMBAT VALUE  NOTEPAD  HOOKBOOK
A place to leave notes on system design and improvement for the manager.
```

Figure 10. Input Parameter Change Menu

```
NUMBERS  CAPABILITIES  INDICATORS  WEIGHT  SUPPLIES  NOTEPAD  HOOKBOOK
 Use to set Number of Units Available for the Deployment

NUMBERS  CAPABILITIES  INDICATORS  WEIGHT  SUPPLIES  NOTEPAD  HOOKBOOK
Use to set Firepower, Anti-Tank, and Defensive Frontage Capabilities

NUMBERS  CAPABILITIES  INDICATORS  WEIGHT  SUPPLIES  NOTEPAD  HOOKBOOK
Use to set Combat vrs Combat Support and Airdrop Indicators

NUMBERS  CAPABILITIES  INDICATORS  WEIGHT  SUPPLIES  NOTEPAD  HOOKBOOK
To set Tons of Outsize, Oversize and Bulk and Numbers of Personel per Unit

NUMBERS  CAPABILITIES  INDICATORS  WEIGHT  SUPPLIES  NOTEPAD  HOOKBOOK
Use to set Daily Tons of Supplies Consumed by Units

NUMBERS  CAPABILITIES  INDICATORS  WEIGHT  SUPPLIES  NOTEPAD  HOOKBOOK
Move to the notepad where notes can be entered, reviewed, printed or deleted.

NUMBERS  CAPABILITIES  INDICATORS  WEIGHT  SUPPLIES  NOTEPAD  HOOKBOOK
A place to leave notes on system design and improvement for the manager.
```

Figure 11. Input Units Change Menu

```
DISTANCE     RAMP     MATERIAL HANDLING     NOTEPAD     HOOKBOOK
Use to Change Distance Between US and APOD of FOL, and APOD and FOL

DISTANCE     RAMP     MATERIAL HANDLING     NOTEPAD     HOOKBOOK
Use this to set Airfield Ramp Capacities for APOD and FOL

DISTANCE     RAMP     MATERIAL HANDLING     NOTEPAD     HOOKBOOK
Use this to set Material Handling Equipment Levels at APOD and FOL

DISTANCE     RAMP     MATERIAL HANDLING     NOTEPAD     HOOKBOOK
Move to the notepad where notes can be entered, reviewed, printed or deleted.

DISTANCE     RAMP     MATERIAL HANDLING     NOTEPAD     HOOKBOOK
A place to leave notes on system design and improvement for the manager.
```

Figure 12. Input Airfield Change Menu

```
FOR AC NUMBERS  USAGE   PERFORMANCE   CARGO   ATTRITION   NOTEPAD  HOOKBOOK
Use this to Change the Number of any Type Aircraft in This Model

FOR AC NUMBERS  USAGE   PERFORMANCE   CARGO   ATTRITION   NOTEPAD  HOOKBOOK
Use this to Change the Usage (round trip times) of Each Aircraft Type

FOR AC NUMBERS  USAGE   PERFORMANCE   CARGO   ATTRITION   NOTEPAD  HOOKBOOK
Use this to Change Ute Rates, Airspeeds and Ground Times

FOR AC NUMBERS  USAGE   PERFORMANCE   CARGO   ATTRITION   NOTEPAD  HOOKBOOK
To Change Tons of Each Type Cargo, Number of Pallets and Ease of Offload

FOR AC NUMBERS  USAGE   PERFORMANCE   CARGO   ATTRITION   NOTEPAD  HOOKBOOK
To set the Attrition Rate for each Aircraft and Mission Type

FOR AC NUMBERS  USAGE   PERFORMANCE   CARGO   ATTRITION   NOTEPAD  HOOKBOOK
Move to the notepad where notes can be entered, reviewed, printed or deleted.

FOR AC NUMBERS  USAGE   PERFORMANCE   CARGO   ATTRITION   NOTEPAD  HOOKBOOK
A place to leave notes on system design and improvement for the manager.
```

Figure 13. Input Aircraft Change Menu

```
DECISION    CONSTRAINT    RANGE  NOTEPAD  HOOKBOOK
Use to Look at the Column of Decision Variable Names

DECISION    CONSTRAINT    RANGE  NOTEPAD  HOOKBOOK
Use to Look at the Row of Constraint Names

DECISION    CONSTRAINT    RANGE  NOTEPAD  HOOKBOOK
Use to Look at the Column of Lotus Range Names and Locations in this Model

DECISION    CONSTRAINT    RANGE  NOTEPAD  HOOKBOOK
Move to the notepad where notes can be entered, reviewed, printed or deleted.

DECISION    CONSTRAINT    RANGE  NOTEPAD  HOOKBOOK
A place to leave notes on system design and improvement for the manager.
```

Figure 14. Input View Menu

As mentioned earlier the last item in the menu hierarchy will take the user to a data base screen display. All of these displays have been presented earlier in Tables I through XIII of chapter III. On all thirteen of these displays operations, memory aids, and control mechanisms are provided for the user in an area of the display which contains a list of commands used to return to various menus. Returning to a menu is as easy as holding down the alt key and pressing the letter for the menu desired. These alt x commands are displayed in green to draw attention to their location. The commands being displayed and the explanation of the command serve as memory aids to the user. While displaying a data base table, the user can change a data base item by: first, using the arrow keys to select the item, second, typing the new entry, which then appears on the top line of the spreadsheet, and lastly, pressing return.

Output Menus. The menus of the output spreadsheet are presented in Figures 15 through 20. These menus are presented in the same way as the input spreadsheet menus.

```
VIEW     CHANGE   OUTPUT   NOTEPAD   HOOKBOOK QUIT
Use to Look at Decision, Constraint, or Range Names

VIEW     CHANGE   OUTPUT   NOTEPAD   HOOKBOOK QUIT
Use to Change Paramaters or Formulation Constraints.

VIEW     CHANGE   OUTPUT   NOTEPAD   HOOKBOOK QUIT
Use to Select Output Analysis Menu.

VIEW     CHANGE   OUTPUT   NOTEPAD   HOOKBOOK QUIT
Move to the notepad where notes can be entered, reviewed, printed or deleted.

VIEW     CHANGE   OUTPUT   NOTEPAD   HOOKBOOK QUIT
A place to leave notes on system design and improvement for the manager.

VIEW     CHANGE   OUTPUT   NOTEPAD   HOOKBOOK QUIT
Quit the DSS Menu and Return to Lotus 123
```

Figure 15. Output Main Menu

```
PARAMETERS   FORMULATION   NOTEPAD   HOOKBOOK
Use to Change Aircraft Airdrop or Rigger Capacities, and Unit Indicators.

PARAMETERS   FORMULATION   NOTEPAD   HOOKBOOK
Places You at the Constraint Matrix for Manually Reworking Formulations

PARAMETERS   FORMULATION   NOTEPAD   HOOKBOOK
Move to the notepad where notes can be entered, reviewed, printed or deleted

PARAMETERS   FORMULATION   NOTEPAD   HOOKBOOK
A place to leave notes on system design and improvement for the manager.
```

Figure 16. Output Change Menu

```
VARIABLES  CONSTRAINTS  AC SORTIES  PAYLOADS  GRAPH  NOTEPAD  HOOKBOOK
Use to Look at Column of Decision Variable Activity and Reduced Cost.

VARIABLES  CONSTRAINTS  AC SORTIES  PAYLOADS  GRAPH  NOTEPAD  HOOKBOOK
Use to Look at Rows of Constraint Left-hand Sides and Dual Value.

VARIABLES  CONSTRAINTS  AC SORTIES  PAYLOADS  GRAPH  NOTEPAD  HOOKBOOK
Use to Look at Table of Total Aircraft Sorties by Aircraft Type per Period.

VARIABLES  CONSTRAINTS  AC SORTIES  PAYLOADS  GRAPH  NOTEPAD  HOOKBOOK
Use to Look at Table of Total Aircraft Sorties by Cargo Type per Period.

VARIABLES  CONSTRAINTS  AC SORTIES  PAYLOADS  GRAPH  NOTEPAD  HOOKBOOK
Use to get to Chart Menu for Chart Options

VARIABLES  CONSTRAINTS  AC SORTIES  PAYLOADS  GRAPH  NOTEPAD  HOOKBOOK
Move to the notepad where notes can be entered, reviewed, printed or deleted.

VARIABLES  CONSTRAINTS  AC SORTIES  PAYLOADS  GRAPH  NOTEPAD  HOOKBOOK
A place to leave notes on system design and improvement for the manager.
```

Figure 17. Output, Output Menu

```
VIEW    SAVE    PRINT    INPUTS    NOTEPAD   HOOKBOOK
Use to View a Graph.

VIEW    SAVE    PRINT    INPUTS    NOTEPAD   HOOKBOOK
Use to Save Current Graph to a Picture (.PIC) File.

VIEW    SAVE    PRINT    INPUTS    NOTEPAD   HOOKBOOK
To Print a Graph, Save it and Exit the Spreadsheet, Use Lotus Printgraph.

VIEW    SAVE    PRINT    INPUTS    NOTEPAD   HOOKBOOK
To Look at the Spreadsheet Area With all Graph Inputs.

VIEW    SAVE    PRINT    INPUTS    NOTEPAD   HOOKBOOK
Move to the notepad where notes can be entered, reviewed, printed or deleted.

VIEW    SAVE    PRINT    INPUTS    NOTEPAD   HOOKBOOK
A place to leave notes on system design and improvement for the manager.
```

Figure 18. Graph Menu

```
SORTIES  A. C-17 PAYLOADS  B. C-141 PAYLOADS  NOTEPAD  HOOKBOOK
Use to View Graph of AC Sorties by Mission Type, PRESS RETURN and Q When Done.

SORTIES  A. C-17 PAYLOADS  B. C-141 PAYLOADS  NOTEPAD  HOOKBOOK
Use to View Graph of C-17 Sorties by Payload Type.

SORTIES  A. C-17 PAYLOADS  B. C-141 PAYLOADS  NOTEPAD  HOOKBOOK
Use to View Graph of C-141 Sorties by Payload Type.

SORTIES  A. C-17 PAYLOADS  B. C-141 PAYLOADS  NOTEPAD  HOOKBOOK
Move to the notepad where notes can be entered, reviewed, printed or deleted.

SORTIES  A. C-17 PAYLOADS  B. C-141 PAYLOADS  NOTEPAD  HOOKBOOK
A place to leave notes on system design and improvement for the manager.
```

Figure 19. Output Graph View Menu

```
DECISION   CONSTRAINT   RANGE   NOTEPAD  HOOKBOOK
Use to Look at the Column of Decision Variable Names

DECISION   CONSTRAINT   RANGE   NOTEPAD  HOOKBOOK
Use to Look at the Row of Constraint Names

DECISION   CONSTRAINT   RANGE   NOTEPAD  HOOKBOOK
Use to Look at the Column of Lotus Range Names and Locations in this Model

DECISION   CONSTRAINT   RANGE   NOTEPAD  HOOKBOOK
Move to the notepad where notes can be entered, reviewed, printed or deleted.

DECISION   CONSTRAINT   RANGE   NOTEPAD  HOOKBOOK
A place to leave notes on system design and improvement for the manager.
```

Figure 20. Output View Menu

As new uses for this DSS are found new menus can be added and new macros can be created to accomplish the new task. The menus are built in modules which allows changes to be made without affecting any previously developed menus or macros.

Output Interface

The output interface of the DSS is required to be user friendly and easy to understand. The screen displays for the output support the kernel problems, which were identified from the concept maps. The kernels dealt with the allocation of airlift resources. The two questions to be answered were: how many aircraft sorties of what aircraft and mission type are required to maximize combat power delivered to the objective area, and how many aircraft sorties by aircraft and payload type are required per period to maximize combat power delivered to the objective area?

The displays for the output from this DSS are presented in three ways. Either of these can be selected through the output menu.

The first way to view the output is through selecting either variables or constraints from the output menu. The variable selection brings to the screen three columns of data. These three columns contain the variable name, the variable activity and the reduced cost. Table XIV contains the variable output from this run of the DSS model.

Table XIV

VARIABLE OUTPUT

VARABLE NAME	ACTIVITY	REDUCED COST	VARABLE NAME	ACTIVITY	REDUCED COST
FOL11		0.000370	C5AP21		0.061578
FOL12		0.001060	C5AP22		0.280198
FOL13		0.000424	C5AP23		0.202365
FOL14		0.002334	C5AP24		0.171232
FOL21		0.002950	C5AP31		0.151219
FOL22			C5AP32		0.280198
FOL23			C5AP33		0.202365
FOL24			C5AP34		0.171232
FOL31		0.003272	C5AP41		0.185861
FOL32	810.5800		C5AP42		0.280198
FOL33	810.5800		C5AP43		0.202365
FOL34	810.5800		C5AP44		0.171232
FOL41		0.000363	C5AP51		0.151219
FOL42			C5AP52		0.280198
FOL43			C5AP53		0.202365
FOL44			C5AP54		0.171232
FOLS31		0.002526	C17AP11		0.011247
FOLS32			C17AP12	19.74047	
FOLS33			C17AP13	19.73060	
FOLS34			C17AP14	19.72074	
APOD11		0.000352	C17AP21		0.048637
APOD12		0.001060	C17AP22		0.171826
APOD13		0.000424	C17AP23		0.124097
APOD14		0.002334	C17AP24		0.105005
APOD21		0.003131	C17AP31		0.105406
APOD22			C17AP32		0.171826
APOD23			C17AP33		0.124097
APOD24			C17AP34		0.105005
APOD31		0.001870	C17AP41		0.162861
APOD32			C17AP42		0.171826
APOD33			C17AP43		0.124097
APOD34			C17AP44		0.105005
APOD41		0.000353	C17AP51		0.105406
APOD42			C17AP52		0.171826
APOD43			C17AP53		0.124097
APOD44			C17AP54		0.105005
APODS31		0.001870	C17FO11	99.79949	
APODS32			C17FO12		0.000629
APODS33			C17FO13		0.000334
APODS34			C17FO14		0.000105
PAL1	1000		C17FO21		0.043423
PAL2	2000		C17FO22		0.172284
PAL3	3000		C17FO23		0.124307
PAL4	4000		C17FO24		0.105005
C5AP11	90.90909		C17FO31		0.057039
C5AP12	18.09917		C17FO32		0.172284
C5AP13	18.08271		C17FO33		0.124307
C5AP14	18.06628		C17FO34		0.105005

Table XIV (continued)
VARIABLE OUTPUT

VARABLE NAME	ACTIVITY	REDUCED COST	VARABLE NAME	ACTIVITY	REDUCED COST
C17F041		0.147549	C141AP21	28.62753	
C17F042		0.172284	C141AP22	11.74832	
C17F043		0.124307	C141AP23	36.82852	
C17F044		0.105005	C141AP24	6.953079	
C17F051		0.061798	C141AP31		0.019591
C17F052		0.172284	C141AP32		
C17F053		0.124307	C141AP33		
C17F054		0.105005	C141AP34		
C17AD11			C141AP41		0.008871
C17AD12			C141AP42		
C17AD13			C141AP43	3.651196	
C17AD14			C141AP44	2.098030	
C17AD21		0.082128	C141AP51		0.019591
C17AD22		0.172857	C141AP52		
C17AD23		0.124569	C141AP53		
C17AD24		1.229293	C141AP54		
C17AD31		0.025104	C141F021	191.7669	
C17AD32		1.837971	C141F022		
C17AD33		0.124569	C141F023		
C17AD34		0.105005	C141F024		
C17AD41		0.138384	C141F031	16.75422	
C17AD42		0.172857	C141F032	35.33093	
C17AD43		0.684076	C141F033		
C17AD44		0.105005	C141F034		
C17AD51		0.062958	C141F041	12.55965	
C17AD52		0.172857	C141F042		
C17AD53		0.124569	C141F043		
C17AD54		0.105005	C141F044		
C17IN11		0.032143	C141F051		0.002186
C17IN12		0.018316	C141F052		
C17IN13		0.012929	C141F053	10.20637	
C17IN14		0.010500	C141F054		
C17IN21		0.035546	C141AD21		0.030783
C17IN22		0.018316	C141AD22		
C17IN23		0.012929	C141AD23		
C17IN24		0.010500	C141AD24		0.467279
C17IN31			C141AD31		
C17IN32		0.018316	C141AD32		0.764032
C17IN33		0.012929	C141AD33		
C17IN34		0.010500	C141AD34		
C17IN41		0.035826	C141AD41		
C17IN42		0.018316	C141AD42		
C17IN43		0.012929	C141AD43		0.831684
C17IN44		0.010500	C141AD44		
C17IN51	2.005012		C141AD51		0.017369
C17IN52		0.018316	C141AD52		
C17IN53		0.012929	C141AD53		
C17IN54		0.010500	C141AD54		

Table XIV (continued)
VARIABLE OUTPUT

VARABLE NAME	ACTIVITY	REDUCED COST	VARABLE NAME	ACTIVITY	REDUCED COST
C141IN21		0.023009	C130IN51		0.004664
C141IN22			C130IN52		
C141IN23			C130IN53		
C141IN24			C130IN54		
C141IN31		0.006832	NUMC52	7.981818	
C141IN32	35.41970		NUMC53	7.978228	
C141IN33			NUMC54	7.974583	
C141IN34			NUMC172	7.948095	
C141IN41		0.026727	NUMC173	7.946121	
C141IN42			NUMC174	7.944148	
C141IN43			NUMC1412	21.77033	
C141IN44			NUMC1413	21.64408	
C141IN51		0.006940	NUMC1414	21.62173	
C141IN52	8.281029		NUM7472	5.985	
C141IN53			NUM7473	5.982015	
C141IN54	9.627031		NUM7474	5.980015	
C747AP21	69.53362		NUMDC82	3.990090	
C747AP22	9.476155		NUMDC83	3.988113	
C747AP23	3.063555		NUMDC84	3.988113	
C747AP24	9.927112		NUMC1302	12	
C747AP31	2.435081		NUMC1303	12	
C747AP32	0.993711		NUMC1304	12	
C747AP33	0.999623		TRKIN1		
C747AP34	0.643432		TRKIN2		
C747AP51	3.031289		TRKIN3		
C747AP52	4.455132		TRKIN4		
C747AP53	5.958551		AB82FO1		
C747AP54	4.329508		AB82FO2		
DC8AP31	13.86655		AB82F03		
DC8AP32			AB82F04		
DC8AP33			AB82AP1	9	
DC8AP34			AB82AP2		1.832877
DC8AP41	35.68299		AB82AP3		3.832877
DC8AP42	2.240926		AB82AP4		4.632877
DC8AP43			AB82IN1		
DC8AP44			AB82IN2		1.832877
DC8AP51			AB82IN3		3.832877
DC8AP52	7.644432		AB82IN4		4.632877
DC8AP53			HQ82AP1		0.319525
DC8AP54	9.880460		HQ82AP2		
C130IN31		0.004664	HQ82AP3	2.333333	
C130IN32			HQ82AP4		
C130IN33			AASSFO1	4	
C130IN34			AASSFO2		2.326842
C130IN41		0.015344	AASSFO3		5.197409
C130IN42			AASSFO4		6.345636
C130IN43			AASSAP1		0.007256
C130IN44			AASSAP2		2.326842

Table XIV (continued)
VARIABLE OUTPUT

VARABLE NAME	ACTIVITY	REDUCED COST	VARABLE NAME	ACTIVITY	REDUCED COST
AASSAP3		5.197409	MECHIN1		
AASSAP4		6.345636	MECHIN2		
AASSIN1		0.000516	MECHIN3		
AASSIN2		2.326842	MECHIN4		
AASSIN3		5.197409	F16AP1	0.594844	
AASSIN4		6.345636	F16AP2	0.405155	
ARTFO1	1.211796		F16AP3		4
ARTFO2		0.804214	F16AP4		5.6
ARTFO3		2.260292	TRKAP1		5.232757
ARTFO4		2.842723	TRKAP2		
ARTAP1	1.788203		TRKAP3		
ARTAP2		0.804214	TRKAP4		
ARTAP3		2.260292	ALCEFO1		0.465879
ARTAP4		2.842723	ALCEFO2		
ARTIN1			ALCEFO3		
ARTIN2		0.804214	ALCEFO4		
ARTIN3		2.260292	ALCEAP1		0.441064
ARTIN4		2.842723	ALCEAP2		
MECHFO1	1.046918		ALCEAP3		
MECHFO2			ALCEAP4		
MECHFO3			ALCEIN1		0.455707
MECHFO4			ALCEIN2		
MECHAP1	1.749292		ALCEIN3		
MECHAP2	0.587728		ALCEIN4		
MECHAP3	0.587291			265.8907	
MECHAP4	0.586853				

The variable activity is the value of the variable at optimality. The reduced cost is the increase in the value of the objective function associated with that variable required for that variable to enter the final basses, if everything else is held constant.

Table XV contains the rows of data assosiated with the constraints selection on the output menu. The rows that appear on the screen contain the constraint name, the constraint activity, and the constraint dual.

Table XV
CONSTRAINT ACTIVITY AND DUAL

ANTI-TANK REQUIREMENT --------
PERIOD

constraint	AT1	AT2	AT3	AT4
activity	180.9265	195.5121	195.5121	195.5121
dual				

-- FRONT LINE TRACE ---------
PERIOD

constraint	FLT1	FLT2	FLT3	FLT4
activity	22.28150	22.28150	22.28150	22.28150
dual				

--- C5 AIRCRAFT GENERATION ---
ONE FOR SORTIE ONE FOR NUMBER OF AIRCRAFT

constraint	C5S1	C52	C5S2	C53
activity	200	40		40
dual	0.122550	0.127208	0.127208	0.091913

constraint	C5S3	C54	C5S4
activity		40	
dual	0.091913	0.077832	0.077832

--- C17 AIRCRAFT GENERATION ---
ONE FOR SORTIE ONE FOR NUMBER OF AIRCRAFT

constraint	C17S1	C172	C17S2	C173
activity	200	40		40
dual	0.093481	0.085856	0.085856	0.062022

constraint	C17S3	C174	C17S4
activity		40	
dual	0.062022	0.052502	0.052502

--- C141 AIRCRAFT GENERATION ---
ONE FOR SORTIE ONE FOR NUMBER OF AIRCRAFT

constraint	C141S1	C1411	C141S2	C1412
activity	524.3875	110	-8.83686	110
dual				

constraint	C141S3	C1413	C141S4
activity		110	-87.2099
dual			

--- 747 AIRCRAFT GENERATION ---
ONE FOR SORTIE ONE FOR NUMBER OF AIRCRAFT

constraint	747S1	7471	747S2	7472
activity	150	30		30
dual	0.072802			

constraint	747S3	7473	747S4
activity	-9.77668	30	
dual			

Table XV (continued)

CONSTRAINT ACTIVITY AND DUAL

--- DC8 AIRCRAFT GENERATION ---
ONE FOR SORTIE ONE FOR NUMBER OF AIRCRAFT

constraint	DC8S1	DC81	DC8S2	DC82
activity	99.09909	20	-0.13018	20
dual				

constraint	DC8S3	DC84	DC8S4
activity	-19.8811	20	-0.12020
dual			

--- C130 AIRCRAFT GENERATION ---
ONE FOR SORTIE ONE FOR NUMBER OF AIRCRAFT

constraint	C130S1	C1301	C130S2	C1302
activity		60	-60	60
dual				

: --- AIRCRAFT UTILIZATION RATE
: ONE PER C5 AND PERIOD

constraint	UC51	UC52	UC53	UC54
activity	7.272727	-0.45314	-0.45359	-0.45404
dual				

: --- AIRCRAFT UTILIZATION RATE
: ONE PER C5 AND PERIOD

constraint	UC171	UC172	UC173	UC174
activity	6.686515	-0.70775	-0.70789	-0.70803
dual				

: --- AIRCRAFT UTILIZATION RATE
: ONE PER C5 AND PERIOD

constraint	UC1411	UC1412	UC1413	UC1414
activity	25.39414		-0.69167	-4.18068
dual	0.575570			

: --- AIRCRAFT UTILIZATION RATE
: ONE PER 747 AND PERIOD

constraint	U7471	U7472	U7473	U7474
activity	7.5	-0.02396	-0.51354	-0.02517
dual				

: --- AIRCRAFT UTILIZATION RATE
: ONE PER DC8 AND PERIOD

constraint	UDC81	UDC82	UDC83	UDC84
activity	4.954954		-0.98804	
dual	0.568277			

Table XV (continued)
CONSTRAINT ACTIVITY AND DUAL

	--- AIRCRAFT UTILIZATION RATE ONE PER C130 AND PERIOD			
constraint	UC1301	UC1302	UC1303	UC1304
activity		-20.25	-20.25	-20.25
dual				

	APOD RAMP CAPACITY			
constraint	ARAMP1	ARAMP2	ARAMP3	ARAMP4
activity	1	0.695034	0.633989	0.637336
dual	10.58774			

	FOL RAMP CAPACITY			
constraint	FRAMP1	FRAMP2	FRAMP3	FRAMP4
activity	0.466634	0.123487	0.015947	0.015042
dual				

	APOD MATERIAL HANDLING EQUIPMENT ONE PER PERIOD			
constraint	AMHE1	AMHE2	AMHE3	AMHE4
activity	915.7659	890.4776	394.2624	457.7143
dual				

	FOL MATERIAL HANDLING EQUIPMENT ONE PER PERIOD			
constraint	FMHE1	FMHE2	FMHE3	FMHE4
activity	850.4725	1027.411	132.6829	125.1514
dual				

	82ND AB	82 HQ	Air Assault	Artillery
constraint	U82ND	U82HQ	UAASS	UART
activity	9	2.333333	4	3
dual	9.032877		12.66088	6.046094

	Mechanized M1	F16	Medium Truck	Air Force ALCE
constraint	UMECH	UF16S	UTRK	UALCE
activity	4.558084	1		
dual		14.4		

Table XV (continued)
CONSTRAINT ACTIVITY AND DUAL

constraint	APOUT1	APOUT2	APOUT3	APOUT4
activity				
dual	-0.00417	-0.00381	-0.00275	-0.00233
constraint	APOVR1	APOVR2	APOVR3	APOVR4
activity				
dual	-0.00313			
constraint	APBLK1	APBLK2	APBLK3	APBLK4
activity				
dual	-0.00187			
constraint	APPER1	APPER2	APPER3	APPER4
activity				
dual	-0.00035			
constraint	APFOOUT1	APFOOUT2	APFOOUT3	APFOOUT4
activity				
dual	-0.00000			
constraint	APFOOVR1	APFOOVR2	APFOOVR3	APFOOVR4
activity				
dual	0.000064			
constraint	APFOBLK1	APFOBLK2	APFOBLK3	APFOBLK4
activity				
dual	-0.00065			
constraint	APFOPER1	APFOPER2	APFOPER3	APFOPER4
activity				
dual	0.000033			
constraint	FOOUT1	FOOUT2	FOOUT3	FOOUT4
activity				
dual	-0.00418	-0.00381	-0.00275	-0.00233
constraint	FOOVR1	FOOVR2	FOOVR3	FOOVR4
activity				
dual	-0.00301			
constraint	FOBLK1	FOBLK2	FOBLK3	FOBLK4
activity				
dual	-0.00262			

Table XV (continued)
CONSTRAINT ACTIVITY AND DUAL

constraint	FOPER1	FOPER2	FOPER3	FOPER4
activity				
dual	-0.00039			

AIRDROP MISSIONS DIRECT TO THE FRONT
One for Each Period and Cargo Type

constraint	ADOUT1	ADOUT2	ADOUT3	ADOUT4
activity				
dual	-0.00420	-0.00385	-0.00277	-0.00233

constraint	ADOVR1	ADOVR2	ADOVR3	ADOVR4
activity				
dual	-0.00223			0.023481

constraint	ADBLK1	ADBLK2	ADBLK3	ADBLK4
activity				
dual	-0.00328	0.033385		

constraint	ADPER1	ADPER2	ADPER3	ADPER4
activity				
dual	-0.00049		0.005499	

SUPPLIES TO THE APOD
One For Each Period

constraint	SUPAP1	SUPAP2	SUPAP3	SUPAP4
activity	200	200	200	200
dual	-0.00187			

SUPPLIES TO THE FRONT
One For Each Period

constraint	SUPFO1	SUPFO2	SUPFO3	SUPFO4
activity	100	100	100	100
dual	-0.00252			

TRUCK UNIT SHIPMENTS
Restricted to units previously delivered

constraint	SUPTRK1	SUPTRK2	SUPTRK3	SUPTRK4
activity				
dual	-0.00074			

	LINKAGE COMBAT AND SUPPORT	HDQ	RIGGER CONSTRAINTS ONE PER PERIOD			
constraint	LINKSUP	LINKHDQ	RIG1	RIG2	RIG3	RIG4
activity	12.22475	2	1000	1000	1000	1000
dual						

The constraint activity depicted on this display is the value of the left hand side of the constraint at optimality. The dual value is the value that the objective function would increase by if one more unit of that constraint resource was available, everything else remaining the same. These raw data outputs are not necessarily as useful as the next two methods of output.

The second way the output is displayed is in a traditional table form. Table XVI contains the output for the first question and Table XVII contains the output for the second. This form may not be user friendly and in some cases can cause user overload as the user tries to plow through the rows and columns of numbers. However, sometimes this much detail is needed and can show

Table XVI

AIRCRAFT SORTIES PER PERIOD BY AIRCRAFT TYPE AND MISSION TYPE

		INTERTHEATER (US to APOD)				alt m	main
	period				TOTAL	alt o	output
type	1	2	3	4		alt g	graph
C-5	90.90909	18.09917	18.08271	18.06628	145.1572		
C-17	0	19.75	19.74012	19.58811	59.07823		
C-141	0	51.22383	2.100000	43.98628	97.31011		
747	75	14.925	14.91007	14.89516	119.7302		
DC8	49.54954	0	2.498286	2.175389	54.22322		
		INTERTHEATER (US to FOL) INCLUDING AIRDROP					
C-17	100	0	0	0	100		
C-141	242.9956	0	18.95406	7.059333	269.0090		
		INTRATHEATER (APOD to FOL)					
C-17	0	0	0	1.421425	1.421425		
C-141	0	0	1.236334	14.70528	15.94162		
C-130	0	14.93157	0	42.64671	57.57829		
			GRAND TOTAL		919.4495		

Table XVII

AIRCRAFT SORTIES BY PAYLOAD TYPE PER PERIOD

alt m main menu
alt o output
alt g graph

OUTSIZE

ac type	period 1	2	3	4	TOTAL
C-5	90.90909	18.09917	18.08271	18.06628	145.1572
C-17	100	19.75	19.74012	21.00953	160.4996

OVERSIZE

ac type	period 1	2	3	4	TOTAL
C-5	0	0	0	0	0
C-17	0	0	0	0	0
C-141	206.6752	46.13512	4.658379	23.90095	281.3697
747	71.45091	5.677752	12.28706	14.89516	104.3109

BULK

ac type	period 1	2	3	4	TOTAL
C-5	0	0	0	0	0
C-17	0	0	0	0	0
C-141	18.37612	0	4.089876	0.633436	23.09944
747	3.549080	1.626833	0	0	5.175914
DC8	9.971192	0	1.541643	2.175389	13.68822
C-130	0	0	0	0	0

PERSONNEL

ac type	period 1	2	3	4	TOTAL
C-5	0	0	0	0	0
C-17	0	0	0	0	0
C-141	13.58555	5.088705	3.019417	5.002735	26.69641
DC8	34.74502	0	0	0	34.74502
C-130	0	0	0	0	0

SUPPLIES

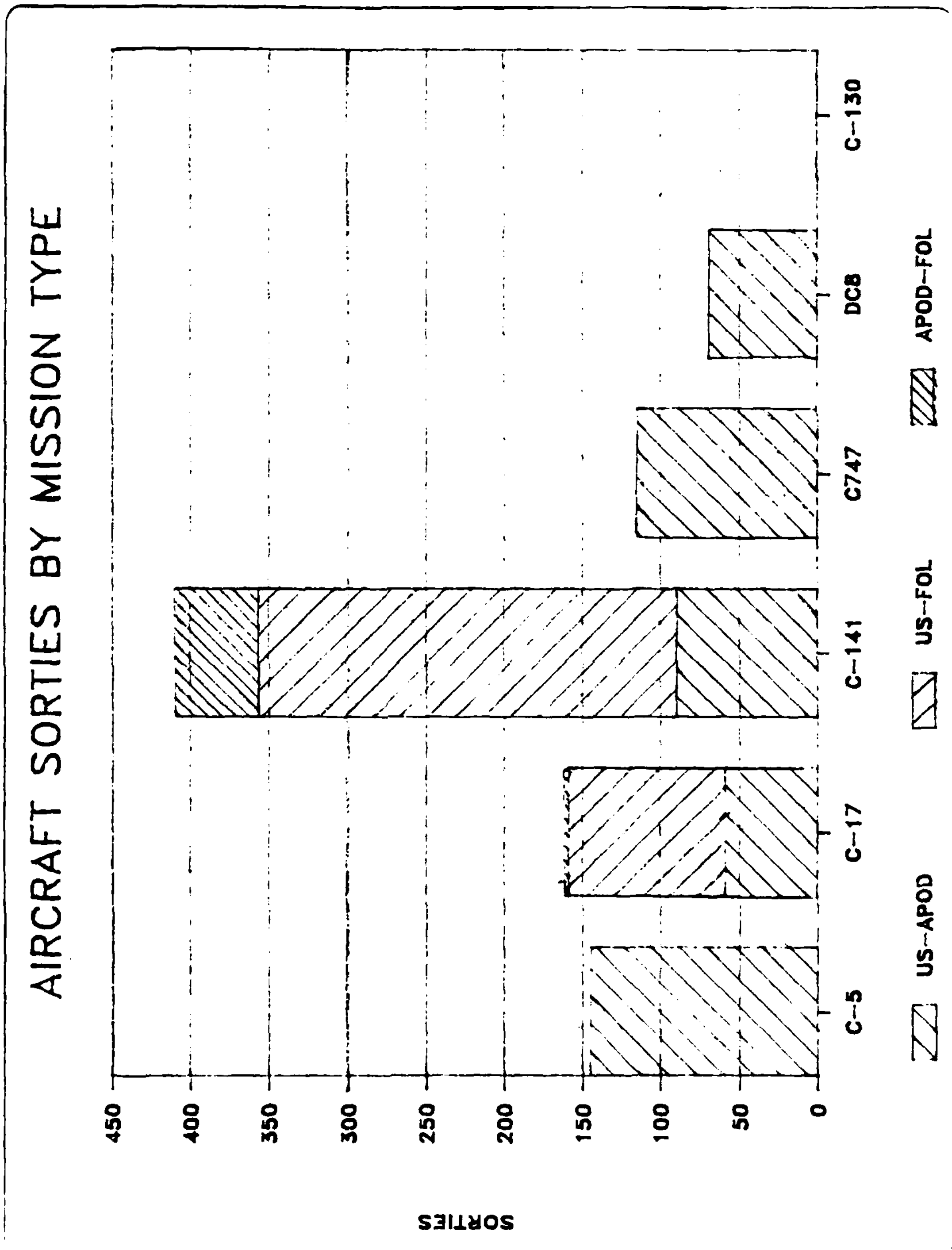
ac type	period 1	2	3	4	TOTAL
C-5	0	0	0	0	0
C-17	0	0	0	0	0
C-141	4.358722	0	10.52273	36.21377	51.09523
747	0	7.620413	2.623008	0	10.24342
DC8	4.833334	0	0.956642	0	5.789976
C-130	0	14.93157	0	42.64671	57.57829

GRAND TOTAL 919.4495

interesting results. On these two tables it is possible to see the shift in aircraft usage as the periods progress.

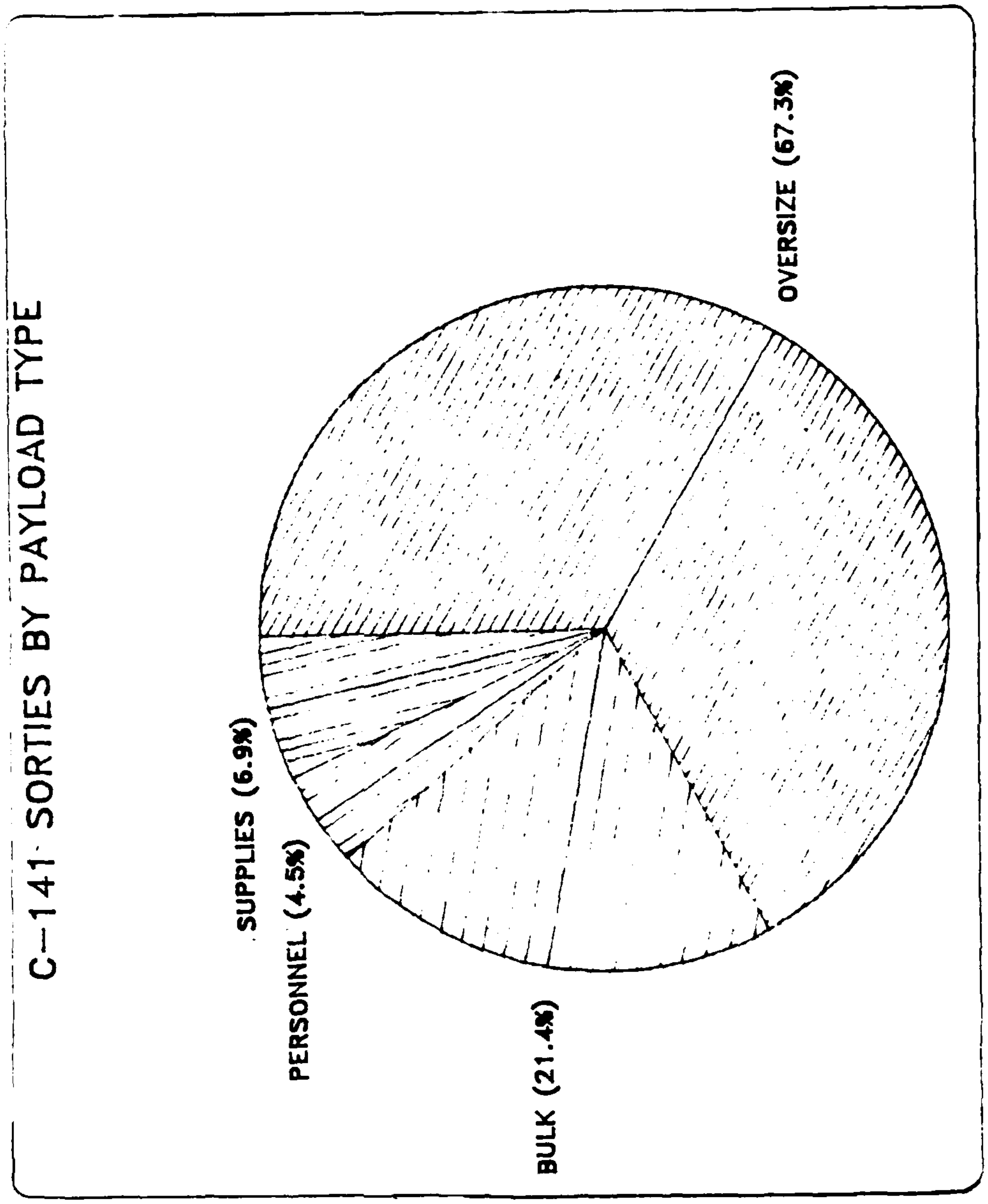
A third form of output, which many consider to be superior to the one just discussed, is graphical output. Figures 21 and 22 show the graphical output built into this DSS. The graphs are of aggregated data and do give easy-to-grasp summaries of the output of the DSS. Another user-friendly aspect of this DSS is that the user does nothing to create these graphs, he just selects them from the menu and they are on his screen. The user can select save from the graph menu and save the most recent graph as a picture (.PIC) file to be printed with Lotus Printgraph. The DSS can be modified in less than five minutes to accommodate new graphical output identified by the user.

Figure 21



AIRCRAFT SORTIES BY MISSION TYPE
SORTIES
450
400
350
300
250
200
150
100
50
0
C-5
C-17
C-141
C747
DC8
C-130
US-APOD
US-FOL
APOD-FOL

Figure 22


C—141 SORTIES BY PAYLOAD TYPE
OVERSIZE (67.3%)
SUPPLIES (6.9%)
PERSONNEL (4.5%)
BULK (21.4%)

Summary

This chapter presented the man machine interface of this DSS. The feature charts were presented first along with a discussion of the notepad and hookbook. The menus were presented along with their explanations and were followed by a discussion of the input and output screens of the DSS.

This chapter was the last of three chapters which described the three components of the DSS. The next chapter will discuss the evaluation and validation of this DSS, and conclussions and recommendations of this research.

VI. *Results, Restrictions, and Recommendations*

Introduction

This chapter serves three purposes. The first purpose is to present the results of the research effort and relate them to the objectives of this research. The second purpose of this chapter is to present the restrictions associated with this DSS. These restrictions are due to the limitations of the components and the software of the DSS. The third and final purpose of this chapter is to suggest some recommendations for further research.

Results

In this section the results of this research effort are examined. First, the results are presented as they relate to the research objectives that have been stated in chapter I. Each objective is restated and followed by a discussion of how the findings of the research effort met that objective. Second, the validation of the research and the evaluation of the DSS are discussed.

Objectives and Findings.

1. To use adaptive design in building a decision support system (DSS) which incorporates this mathematical programming model.

The primary method of design for this DSS was the adaptive design approach as discussed in detail in chapter II. This thesis presents one complete cycle of the adaptive design approach with a working prototype as the result.

2. To solicit specific user, HQ MAC Analysis Group, requirements.

Three separate trips were made to visit the HQ MAC Analysis Group. The first trip was made at the beginning of this research effort to ascertain the extent of interest of members of the Analysis Group in this effort. The second trip was made during the initial design stages of the DSS. The purpose of this trip was to identify the requirements of the Analysis Group by using the concept mapping technique and to develop the storyboards for this DSS. Analysis Group inputs were also solicited for the model improvments. The third visit to Hq MAC was used to present the complete prototype to the Analysis Group and other interested parties.

3. To improve the modeling of attrition.

This was a recommendation made by Haile in his thesis. This was the primary improvement made to the mathematical programming model. This improvement as well as the other improvements made to the formulation have all been identified and described in detail in Chapter IV the model base chapter.

4. To adapt the model to accommodate a spreadsheet to input parameters and output results.

The accomplishment of this objective was a big factor in the successful building of this DSS. Using Lotus

123 as the DSS generator allowed the input parameters and output results to be displayed in user friendly tabular form.

5. To develop a matrix generator to easily generate the input matrix, objective function, and right hand side for the model.

This objective has been acomplished and was a major portion of the effort put into building the DSS. Areas of the two spreadsheets required for this DSS have been set aside for the matrix for the mathematical programing formulation. The matrix, objective function, and right hand side have been built into the spreadsheet in such a way that the user does nothing to change the matrix for the formulation. The user simply changes the values in the parameter tables and the matrix is updated automatically.

The next three objectives six, seven, and eight are discussed together.

6. To identify the size of formulation required to expand the model from the current four five-day periods to thirty one-day periods.
7. To identify the requirements to expand the model to include more than one aerial port of debarkation (APOD) and forward operating location (FOL) .
8. To develop the formula that will determine the size of the problem and how the problem grows in size with each of the changes to be made.

This entire discussion on increases in size of the formulation was presented in the model size section of chapter IV. How quickly the size of the problem grows with various changes in the formulation shows that changes should be studied carefully so the limits of the software are not exceeded.

9. To identify with the help of the user and a technique called concept mapping an initial problem to solve as an illustration of the application of this DSS.

With the help of the concept mapping technique two kernels were identified as the areas for this prototype DSS to study. Captain Mark Fowler of the Hq MAC Analysis Group was the user that participated in the concept mapping.

The application of this DSS to the study of the kernel problems identified is presented throughout this thesis. All the tables of chapter three represent the data base that was used in the prototype application of this DSS. Tables XVI and XVII, and Figures 21 and 22 of chapter V are the output of the DSS for the kernel problems. The objective of this thesis was to demonstrate a representative application not to do an actual study.

Validation and Evaluation. Both validation and evaluation are ongoing processes with the adaptive design approach. Validation has begun with the various parameters being changed and the model run a dozen times. The values of the variables and constraints at optimization have been checked and seem consistent with the assumption of the model.

The primary evaluation process of this DSS is by reviewing the hookbook entries made by the user. The user will leave messages on system performance and needed modifications in the hookbook. The builder/designer will review these entries and make the improvements when necessary.

The adaptive design process is an ongoing, iterative process which requires the prototype to be used and modifications and additions to be identified. This DSS has been presented to the Analysis Group (AG), the Advanced Concepts Requirements Agency (ACRA), and the War Plan Verification Group (XOS) at HQ MAC, and the Studies and Analysis Branch (J5) of USTRANSCOM. Implementation and subsequent iterations of the adaptive design seem likely.

Restrictions

This section discusses restrictions on the use of this DSS. These restrictions include model based restrictions and software/hardware restrictions.

Model Restrictions. The restrictions on the use of the DSS due to the model are all due to the assumptions that are built into the model. It is extremely important to take into account the assumptions built into the model for any analysis that uses the model. The assumptions that pertain to the variables, constraints, and formulation are all outlined in chapter IV.

Software/Hardware Restrictions. This DSS was designed on a Zenith 248, IBM AT compatible computer. The software used was Lotus 123, as the DSS generator, and XA as the mathematical programming solver.

The limitations with MS DOS and Lotus caused the DSS to require two spreadsheets. The first was used primarily for input while the second contains some of the input and all of the output of the DSS. There is still about 40% of the usable space on the output spreadsheet to add new output tables. If changes to the formulation require new variables and constraints (in this case rows and columns) to be added to the mathematical programming matrix then the DSS may have to be spread over additional spreadsheets.

The limits that the XA linear programming software bring to this DSS are with respect to the number of variables and constraints in the formulation. The largest version of the XA software available can accommodate 1000 constraints and 5000 variables. The current version of this DSS with 338 variables and 180 constraints is well below the limits but as stated earlier to go to 30 periods would require 1324 constraints which is above the limits of XA.

The computer run time could be a restriction with increased formulation size. The various runs of the current DSS took anywhere from a few seconds to 20 minutes to solve. XA is fast and does save the solution from the previous run to use as a start for a subsequent run.

This section has emphasized the fact that there are assumptions built into this DSS and that these assumptions must be taken into account when using this DSS. Also, this section has presented some restrictions on this DSS due to the software and hardware used in the development on this DSS.

Recommendations

There are two major recommendations for future research that pertain to the DSS presented in this thesis.

1. This thesis has presented one complete cycle in the adaptive design process, with the prototype DSS having been presented to various users. A specific user, possibly one whom the DSS has been presented to, could be identified and the adaptive design process continued with a second iteration of the process. Improvements and modifications to the DSS should come from the user.

2. This DSS could be used to accomplish a specific study for a particular user. In essence the researcher would become the user of the DSS and would identify a specific study to be accomplished with the DSS. An example of this is the type of analysis Haile accomplished with an earlier version of the model.

Noticeable missing from these recommendations are any specific recommendations dealing with modifications to this DSS or its data base and model base. This is intentional as the adaptive design process requires these types of recommendations to come from the user.

Summary

This thesis has produced a working prototype DSS to assist Air Force and Army Planners. The primary method of design for this DSS was to use the adaptive design approach. This thesis presents one complete cycle of that approach with a working prototype as the result. The concept mapping technique was used to identify two kernel problems for this prototype DSS to study. The three components of this DSS, the data base, the model base, and the man machine interface, are described in detail.

The data base component consists of the various screen displays which contain tabular data. References for the sources of the various data items are given. The data base consists of the input required to the model base component.

The heart of this DSS is the model base which has been adapted from previous thesis efforts. The current form of the model is a linear programming model which contains 180 constraints and 330 decision variables. Central to the development of this DSS was the development of a matrix generator to generate the input to the linear programming package. Lotus 123 was used as a DSS generator and to generate the input for the linear programming software called XA. The user of this DSS simply changes the data items in the data tables and the matrix for the linear program is automatically updated.

The man-machine interface is the third component of the DSS and allows the DSS to function as an interactive user friendly system. This component contains menus and descriptions for individual menu items for both the input and output spreadsheets, the hookbook and notepad, and tabular and graphical output screen displays. All input data screen displays contain text to remind the user of commands available to return him or her to various menus. A command to allow easy printing of any part of the spreadsheets is included. The hookbook and notepad are scratch pads within the spreadsheet where the user can leave messages for himself or the system designer. To study the kernel problems tabular and graphical output are both included. Depending on the level of detail required the user can look at either the raw data output, each variable and constraint value, or the tabular output, aggregated data for various sorties, or the graphical output, aggregated even more than the tabular output.

The last chapter presented the results and findings of this research. It also included a summary of the restrictions associated with this DSS. Lastly, recommendations for future research were presented.

Appendix

This is a short users guide designed for the user that might be unfamiliar with the operation of Lotus 123 and XA and is intended to allow easy use of the ACAR DSS. The system was built on a Zenith 248 computer (IBM AT compatible).

To modify the ACAR data base spreadsheet the user would first enter Lotus 123 by typing LOTUS and selecting return. When the Lotus screen appears use the arrow key to highlight 123 and select return, you should now have a blank spreadsheet on the screen. Lotus commands are invoked by using the / key to call up the menus. Menu items are selected by using the arrows to highlight and return to select or by pressing the first letter of the menu item desired. To call up the ACAR spreadsheets press /fr (for file retrieve) use the arrow keys to highlight either ACAR1 or ACAR2 and press return. The ACAR screen appears and the ACAR menus are automatically available at the top of the screen. ACAR menus are selected the same way as Lotus menus. To call back a menu hold the alt key and press the letter of the menu desired.

Sections of the spreadsheet can be printed by holding the alt key and pressing p, then use arrows to highlight the material to be printed and press return.

When finished with changes in the spreadsheet select /fs (to save the file). Exit 123 with /q and a yes. Exit Lotus by highlighting exit and pressing return.

To invoke the XA mathmatical programing optimization simply type ACAR and a batch file will be started, the matrix will be read, and the answers will be placed in the ACAR2 spreadsheet. A file titled ACAR.OUT will also be created with the standard XA output.

Use the same procedure to get back into Lotus and call up the ACAR2 spreadsheet. After viewing a particular graph and if saving it is desired select save from the graph menu and name your graph with a .pic extention. To print graphs exit 123 and highlight printgraph select return and follow Lotus printgraph instructions.

It is suggested that you keep the original ACAR disk write protected and in a safe place, use only copies of the original disk for iterations of ACAR.

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VITA

Captain Stephan L. Hager was born on 5 June 1955 in St Louis Missouri. He graduated from high school in St Louis in 1973 and graduated with a Bachelor of Science Degree in Aeronautical Engineering, from Parks College of Aeronautical Technology, of Saint Louis University in August of 1976. At the same time he was commissioned as a Second Lieutenant in the Air Force having completed the Air Force ROTC program.

Captain Hager entered pilot training in June on 1977 and in 1978 was trained as a C-141 pilot and assigned to the 4th MAS at McChord AFB, Wa.

After leaving McChord AFB in 1983 he attended Squadron Officers School and then completed a Masters of Science in Business Administration, from Southern Illinois University, Edwardsville, Ill.

From Jan 84 until Jun 86 Captain Hager was assigned to the 57th MAS at Altus AFB, Ok. While his primary duty was as a C-141 Flight Examiner Pilot other positions held included: 443d MAW Special Presentations, Programs, and Protocol Officer; Squadron Assistant Flight Operations Officer (Mission Scheduler); and Squadron Plans Officer.

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The primary objective of this research is to improve and package a previously developed mathematical programing model to increase its likelihood of acceptance. The model departs from the normal measure of effectiveness of airlift, measuring ton miles per day, and allocates combat and airlift resources to maximize combat power delivered to the objective area (thus the name ACAR). The package selected to build around this model was that of a Decision Support System (DSS).

This thesis has produced a working prototype DSS that can assist Air Force and Army Planners. The primary method of design for this DSS was adaptive design. This thesis presents one complete cycle of that approach. The concept mapping technique was used to identify two kernel problems for this DSS to study. The three components of this DSS, the data base, the model base, and the man machine interface, are described in detail.

The data base component consists of the various screen displays which contain tabular data. The tables group similar items together and contain the input required to the model base component. The heart of this DSS is the model base which has been adapted from previous thesis efforts. Lotus 123 was used as a DSS generator and to generate the input for the linear programing software called XA. This DSS is a user friendly analytical tool.