AERIAL PORT LOCATION STUDY

THESIS

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AFIT/GTM/LAL/97S-2

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Levenchi L. Dingle

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Abstract

This study performed an investigation on determining the appropriate number and locations of continental United States aerial ports. To accomplish this a linear programming formulation was adapted with the optimizing function based on trading off the cost of shipping cargo against port operating costs. Cargo would travel from CONUS origin, through aerial port of embarkation (APOE), to aerial port of debarkation (APOD) at minimum cost to the DOD. The need for the study was precipitated by continued reductions in the military budget, consolidation of defense depots, and the reduction in the number of personnel stationed overseas.

Cargo movement data was extracted from the Transportation Reporting and Inquiry System database for fiscal year 1996. This information was then used as deterministic demand at the APODs from particular origination cities. The demand had to be exactly met in the formulation. Applying the linear program resulted in the recommendation to operate only three aerial ports. They are Travis AFB, CA, Dover AFB, DE, and McGuire AFB, NJ saving over 11 million dollars a year.

AERIAL PORT LOCATION STUDY

I. Introduction

At a time when the United States Armed Forces is reducing its numbers in response to a changing world situation and budgeting constraints, there is a need to readdress the structure of the worldwide cargo distribution system. The military is now emphasizing continental United States (CONUS) based forces with the ability to redeploy on short notice. Of course, with fewer personnel in forward areas, the total supply requirement will decrease. This reduction will precipitate a restructuring of the transportation system.

A major portion of this system consists of aerial ports of embarkation located throughout the United States. When the aerial port distribution network was originally designed, aircraft were of limited range and capability as compared to today's standards. It made sense in the post World War II environment to locate most of the aerial port facilities along the east and west coasts. But today with long-range transport capability of United States Air Force (USAF) and commercial aircraft, a new look at the basing structure is warranted.

In 1989 a study along the lines of this thesis was conducted. It was called the "Optimal Airlift Distribution Study Proposal" (OADS) completed by Greg Holevar, currently at headquarters Air Force Material Command in the transportation directorate. The OADS study had some interesting results. At that time, the current locations considered were the eight major aerial ports plus two inland bases. They were Charleston AFB, Charleston, SC; Dover AFB, Dover, DE; McChord AFB, Tacoma, WA; Norfolk NAS, Norfolk, VA; Norton AFB, San Bernadino, CA; Tinker AFB, Oklahoma City, OK; Travis AFB, Fairfield, CA; McGuire AFB, Wrightstown, NJ; Kelly AFB, San Antonio, TX; and Hill AFB, Ogden, UT. After consideration of cargo origin, destination, and aerial port effectiveness in handling the calendar year (CY) 1988 cargo, the study recommended a few changes. The optimal locations of ports were determined to be Charleston, Dover, Norfolk, Tinker, and Travis. It was recommended that McGuire and McChord downsize for a wartime role and that Norton close its doors (1).

Specific Problem

Since 1989, at the completion of the OADS and its implementation beginning in 1990, there have continued to be drastic reductions in personnel and base infrastructure. These are the results of continued tightening of the Department of Defense (DOD) budget and Base Realignment and Closure Commission (BRAC) impacts. Bases overseas and in the CONUS are still being shut down or realigned to include the depots and air logistics centers (ALCs), from which most of the cargo originates that enters into the Defense Transportation System (DTS). As a result of BRAC 95, several depots are slated for closure by the year 2001. The current list of Defense Distribution Depots or Facilities contain 24 sites. Those depots scheduled to close in 1997 include Letterkenny, PA, Ogden, UT, Columbus, OH, and Memphis, TN. The depot at McClellan AFB, CA, and the San Antonio ALC (SA-ALC) at Kelly AFB, TX, are scheduled for closure in 2001 (2). As the independent service depots continue to merge into the Defense Logistics Agency (DLA), the number of cargo origination points will constrict even further necessitating another look at port location.

Today's environment is a reflection of a similar situation in 1989 and 1990. As taken from Annex Alfa to MAC (Military Airlift Command) Programming Plan 90-16, this quote sums up the situation:

> Current and future [DOD] budget constraints require a closer look at the current way of doing business. The existing and future constraints on Second Destination Transportation funding...[and] MAC's task of meeting the time standards set by the Uniform Material Movements and Issue Priority System (UMMIPS) is becoming an increasing difficult and expensive challenge. (3)

According to Mr. Steffey (4), at HQ AMC Cargo Management, approximately 50 percent of the cargo handled by AMC is currently not meeting the Uniform Material Movement and Issue Priority System (UMMIPS) requirements. As a result of this and other tumultuous changes occurring within the DOD, Air Force Materiel Command (AFMC) and Air Mobility Command (AMC) determined that it was again time to address the DTS structure and more specifically the basing strategy of the CONUS aerial port system. The results may be the more efficient and effective handling of the millions of shipments that cross AMC's path annually.

Research Scope

This thesis will analyze the cargo data provided by the Transportation Reporting and Inquiry System (TRAIS) (5) to determine the origin and aerial port of debarkation of the majority of the cargo that transit the DTS system for overseas delivery via AMC's aerial ports. The purpose of this effort will be to locate a best set of CONUS aerial port facilities. The set of alternatives include six major aerial ports in existence today along with three interior possibilities.

Using this synthesis of TRAIS information, a linear programming algorithm will be developed to enumerate and locate a possible set of aerial port facilities to handle the Second Destination cargo requirement.

Model formulation will be based on a transshipment facility location problem which locates intermediate service facilities to minimize some objective cost function, or in this case, the total cost of shipping cargo through the aerial port system en route to the final destination considering operating costs of the aerial ports.

Research Questions

There are two questions which this thesis will answer.

1. Based on a modified distribution system location problem, what are the optimal locations and how many aerial port facilities are needed?
2. How does the new structure compare, on the basis of cost, with the current APOE structure?

Chapter III will discuss the methodology used to answer the above questions.

Summary and Overview

This chapter has given a brief introduction and background to the subject of aerial port facility location. It has also addressed the specific problem, research scope, and the questions that will be answered as a result of this effort. Chapter II will review the literature expounding on location problems in general on down to the focused task at hand. The methodology will be the thrust of Chapter III, which will yield the results in Chapter IV and conclusions in Chapter V.

II. Literature Review

Facility location problems have been the subject of research for quite some time. Advances in computing power in the last 10 to 15 years have caused a resurgence in the genre. For excellent discussions of the basic facility location problems and models, three sources come to mind. The first is a textbook on discrete location theory by Mirchandani and Francis (6) and the second is a text on facility layout and location analysis by Francis, McGinnis, and White (7). Another good treatment of the subject was authored by Love, Morris, and Wesolowsky (8).

Mirchandani and Francis narrow their focus to discrete location decisions as opposed to continuous location decisions:

> The major reasons are that in most cases decision-makers consider a discrete representation to be a more realistic and a more accurate portrayal of the problem at hand, and that continuous formulations appear to be relatively difficult to solve. (6)

They present formulations of and solution methods for the basic models and their variations. These would include the p-median, the p-center, the uncapacitated facility location, and the quadratic assignment problems (6).

Francis et al. discuss both planar single and planar multifacility location problems. They also describe transportation network setups, to include the tree, median, center, covering, and warehouse location problems (7).

Facility location models' main purpose is to quantitatively evaluate the alternatives of siting facilities, be they warehouses, plants, etc., to minimize the cost or some other objective. Models are mathematical optimization techniques that can be used to determine whether or not a facility should be opened or closed, and where they should be placed (9).

The numerous assumptions made that simplify any particular application, ultimately determine the solution generated by the model. One assumption in many location models is that the demand to be satisfied by particular facilities are fixed and known (9). Estimates of capacities and costs are also used. The costs may be divided into transportation, fixed, or operating, with the assumption of linearity for the transportation portion. Therefore, the accuracy and quality of results are heavily dependent on the realism associated with these assumptions.

Another point to be made about facility location models is that although primarily quantitatively based, qualitative factors can be input and evaluated in some formulations (10). Qualitative factors could include such things as does a site have favorable tax laws, a large labor pool, or access to recreational activities? Researchers speaking on the added flexibility of location-allocation models, expound on the fact that these models have the ability to represent wide ranging environments in mathematical terms (9).

For those interested in a brief history of the classic Euclidean minisum distance facility location problem or more succinctly known as the Weber problem, Wesolowsky's "The Weber Problem: History and Perspectives," is a good starting point (11). He breaks down problem development chronologically and credits those who contributed to its present form and understanding. From Fermat (1601-1665), Torricelli (1608-1647), and Cavalieri (1598-1647) to the many others from the seventeenth through twentieth centuries, Wesolowsky gives a substantial overview of the spatial median (Weber) problem history. He then discusses the generalization of the Weber problem to the location-allocation model, where points to be located are facilities and fixed points in the formulation become supply and demand points. Transportation costs were included as functions of distance and mention was made of spherical distances as opposed to Euclidean distances (11). Continuing with the theme of location-allocation models, Ghosh and Harche (9) also review their progress over time.

Ghosh and Harche begin from the introduction of location-allocation models in the 1960s and follow their evolution to the 1990s. They cite the most important characteristic as "the ability of these models to determine the optimal location of several facilities simultaneously."

In many distribution systems some of the located facilities are used as transshipment points which collect goods from dispersed suppliers and then ship to demand points. The same objective is apparent for placing these transshipment centers as is the case for most location problems, that being the minimization of cost (9). Before continuing with transshipment centers, a brief overview of some location analysis that has been applied in military decision-making will be discussed.

Despite the tremendous amount of literature on facility location models, there has been very little work done on the placement of military consolidation points within the continental United States. The "Optimal Airlift Distribution Study (1)," discussed in Chapter I, was the first attempt at locating CONUS aerial ports. The remaining studies found in the literature search that concentrated on military location applications were not specifically directed at the aerial port location problem. The majority was found in the stack of theses at the Air Force Institute of Technology (AFIT). Garcia developed and applied a coverage type location-allocation problem to the locating of Air Force repair facilities and the associated limited reparable equipment stocking those facilities (12). Merrill tackled a single facility location and routing problem in order to site and minimize the en route distance of flight inspection missions. He modified and applied the classic "multiple traveling salesman" model and solved using the Simplex solution method (13).

More in line with the aerial port location task at hand, a thesis was done on the location and routing of the Defense Courier Service (DCS) Aerial Network. The DCS is an organization whose purpose is to handle and transport sensitive material for the Department of Defense. Again the traveling salesman formulation was used but the starting point was Laporte's algorithm input as an integer linear program and a combined heuristic technique, minimum spanning forest/Clarke-Wright, was applied to obtain a solution (14).

The remaining portion of this chapter will briefly describe two formulations of the multiple transshipment center location problem. These models could be applicable to the AMC aerial port network and solved within a given set of constraints.

Model 1: Automobile Manufacturer

In 1992 a study was conducted on behalf of an American automobile manufacturer to locate an appropriate number of transshipment centers. These centers would serve as consolidation points for small Just-in-time shipments from hundreds of suppliers. The material could then be transported to assembly plants in a more cost-effective manner. Bhaskaran's approach to this particular problem was taken as a continuous space model as opposed to a network model (15). Network models have a specified set of alternate locations to choose the best from, whereas continuous models can locate facilities from an almost infinite solution space.

Bhaskaran's objective was to minimize the total flow-weighted transportation distance of material shipped to the plants. The formulation of this large problem is shown below:

Objective function:

Minimize $Z = w\sum_k\sum_i F_k d_{ki}\delta_{ki} + \sum_j\sum_I F_{ji} D_{ij}$ (2.1)

Subject to:

$$\delta_{ki} = \begin{cases} 1 & \text{if } d_{ki} <= d_{kl} \text{ for all } l \neq I, \text{ and } i <= l \text{ for all } l \text{ such that } d_{ki} = d_{kl}, \\ 0 & \text{otherwise,} \end{cases} \quad (2.2)$$

$$\sum_i \delta_{ki} = 1, \quad (2.3)$$

$$F_k = \sum_j f_{kj}, \quad (2.4)$$

$$F_{ji} = \sum_k f_{kj}\ \delta_{ki} \quad (2.5)$$

Where,

α_i, β_I = location of center I

f_{kj} = flow from supplier k to customer j

d_{ki} = distance between supplier k and center I (spherical distance)

D_{ij} = distance between center i and customer j

w = inbound weight factor

F_k = flow from supplier k

F_{ji} = flow to customer j through center I (15).

In this formulation, w, was used to weight inbound shipments more heavily than outbound shipments. Bhaskaran thought this appropriate due to the "[circuity] of inbound routes and the loading inefficiency of inbound material (relative to outbound material) (15)."

To solve this problem, Bhaskaran used a multiple facility heuristic solution procedure. First, for a given number of centers, he determined the best locations. That is to say that one-center, two-center, and up to twenty-center problems were solved. Of course as the number of centers was increased, savings in total ton-miles were seen, but at a decreasing rate. Also, centers selected from early runs remained good candidates in subsequent runs with a greater number of facilities being placed. In order to choose an appropriate final number of transshipment centers, he introduced a minimum-size requirement and reshuffled the remaining workload as the smallest centers were eliminated. Using this approximate solution method, Bhaskaran determined the best location of facilities and the final count was a total of eight centers (15).

His approach, as previously mentioned, is one method to solve a continuous space model. In the case of aerial port location and this thesis, a finite set of possible APOEs is given and the best locations will be chosen from them.

Therefore Bhaskaran's transshipment center location formulation and solution does not apply to this discrete problem.

Model 2: Multicommodity Distribution System

In 1974 a paper was published concerning the modeling of a very complex multiple facility location problem. This research was not earth shattering but was a different approach as compared to previously applied formulation techniques. The techniques developed by Geoffrion and Graves, were applied and gave very favorable results to large scale real world problems (16).

Their multicommodity distribution system is setup to handle a large number of commodity types produced at several plants. The goal was to satisfy known customer demand within dispersed zones by routing the shipment of various commodities through distribution centers. One stipulation is that a particular customer zone be assigned to one distribution center. By consolidating material at a single facility, economies of scale can be realized for the center to customer portion of the shipment (16).

The problem is formulated as a mixed integer linear program and is illustrated below:

Objective function:

$$\text{Minimize}_{x \Rightarrow 0;\ y,\ z = 0,1} \sum_{ijkl} c_{ijkl} x_{ijkl} + \sum_k [f_k z_k + v_k \sum_{il} D_{il} y_{kl}] \qquad (2.6)$$

Subject to:

$$\sum_{kl} x_{ijkl} <= S_{ij} \qquad \text{for all } ij \qquad (2.7)$$

$$\sum_{j} x_{ijkl} = D_{il} y_{kl} \qquad \text{for all } ikl \qquad (2.8)$$

$$\sum_{k} y_{kl} = 1 \qquad \text{for all } l \qquad (2.9)$$

$$\underline{V}_k z_k <= \Sigma_{il} D_{il} y_{kl} <= V_k z_k \qquad \text{for all } k \qquad (2.10)$$

Linear configuration constraints on y and/or z.

Where,

i	= commodity
j	= plant
k	= distribution center (DC) sites
l	= customer demand zones
S_{ij}	= supply (production capacity) for commodity i at plant j
D_{il}	= demand for commodity i in customer zone l
$\underline{V}_k$, V_k	= minimum, maximum throughput for a DC site
f_k	= fixed cost of DC at site k
v_k	= variable unit cost of throughput for DC
c_{ijkl}	= average unit cost of producing and shipping commodity from plant through DC to zone l
x_{ijkl}	= amount of commodity shipped from plant through DC to customer zone l
y_{kl}	= 1 if DC k serves l, otherwise 0
z_k	= 1 if DC is acquired at k, otherwise 0 (16).

The significance of the "ijkl" subscript variables according to the authors is twofold. First, in some applications it is necessary to keep track of where the original shipment ended up, whereas in previous models the use of the triple subscript lacked this flexibility. Other models used separate variables for plant to center and center to customer shipments "linked by a flow conservation constraint." The second reason is that the variables make the incorporation of direct plant to customer shipments an easy matter if the customer does not also receive material from a distribution center(16).

The overall objective was to meet the given demands of the customer at the least total distribution cost while satisfying all of the constraints. A discrete set of possible locations for the distribution centers was given and the final solution is a subset of these, with particular sizes of facilities solved for and customer zones assigned to them exclusively.

Summary

A basic literature review was conducted and reported within this chapter. A large number of location problems exist in the literature and many address multiple transshipment facility location. But relatively few are applied to military specific examples. This is not a major problem because existing models can and should be modified to fit any number of real life situations.

Of the models investigated in this literature search, the Geoffrion and Graves formulation, except for the multicommodity count, looks like the best formulation for this aerial port analysis. The next chapter will address the modifications necessary to make it applicable to the aerial port location study and the data required as input for the new formulation.

III. Methodology

This chapter describes the methodology used in the completion of this aerial port location analysis. The aerial portion of the Defense Transportation System, consists of aerial ports of embarkation, aerial ports of debarkation, and final consumption locations outside the continental US. Feeding cargo to the APOEs, are the distribution depots and other supply points within the CONUS. In this study, the focus is on that portion of the system composed of the origination cities, APOE transshipment bases, and APOD arrival points. In effect the area under study can be represented as a distribution network and therefore be modeled using one of the techniques explained in the literature review of Chapter II.

One can see that due to the difficulty and exorbitant expense of establishing or moving an APOE, there would only exist a select few locations suitable for the purpose. Good candidates for basing an aerial port would of course include the facilities already established by the DOD along the coastal United States. Those locations are Charleston AFB, SC, Dover AFB, DE, McChord AFB, WA, McGuire AFB, NJ, Norfolk NAS, VA, and Travis AFB, CA. Three additional inland sites were chosen to include in the formulation as alternatives to the current structure. Those additional sites are also established Air Force bases and two contain Defense

Distribution Depots (cargo origination points). The depot bases are Hill AFB, UT, and Tinker AFB, OK. Two of the sites also contain limited aerial port facilities, Tinker AFB, OK and Wright-Patterson AFB, OH. These additional three inland sites taken with the six established APOEs, make up the total solution set considered in this thesis.

Cargo shipment data was taken from the FY96 Transportation Reporting and Inquiry System database and analyzed to incorporate into the model. The summary data was inputted to represent the demand at APODs.

Cost and distance data came from a number of different sources. They will be discussed separately in subsequent sections of this chapter.

Model Formulation

The basic structure of the aerial port distribution system is closely related to the network distribution system modeled by Geoffrion and Graves. Their model was introduced in Chapter II. This multicommodity distribution system is described as having several different commodities produced at dispersed locations. The commodities are shipped via distribution centers to satisfy known demands within different customer zones. Also in the Geoffrion and Graves model, the stipulation is made that one customer location is assigned to one distribution center. This would allow for consolidation of material and therefore favor the realization of economies of scale (16).

In this multicommodity model, possible locations of distribution centers are given. Operating costs for each site are given and transportation costs are assumed to vary linearly with distance shipped. The overall thrust of the problem was to determine the number and location of the distribution centers. This would be based on the least-cost combination of establishing facilities and shipping cargo from supply point, to center, to customer in order to meet the given demand (16).

Some changes to the model per se need to be made in order to apply to the military APOE location problem. First of all, the multicommodity aspect can be likened to a particular city or base of origin. Cargo from one origination point is supplied to various APODs based on previously shipped quantities of material. These previous known amounts are considered a type of "commodity" supplied by a specific origin and are demands. Second, only the most significant origination and destination points were included in the analysis. This reduced the complexity of the problem and still allowed a reasonable representation of the complete system. The mixed-integer linear programming formulation of the aerial port distribution system can be written as follows:

Objective function:

$$\text{Minimize} \quad Z = \sum_{jk} (c_{jk}*d_{jk} + v_j)*x_{jk} + \sum_{kl} c_{kl}*d_{kl}*x_{kl} + \sum_k f_k*z_k \tag{3.1}$$

Subject to:

$$\sum_k x_{jk} \le S_j \quad \text{for all } j \tag{3.2}$$

$$\sum_j x_{jk} = \sum_l x_{kl} \quad \text{for all } k \tag{3.3}$$

$$\sum_k x_{kl} = D_l \quad \text{for all } l \tag{3.4}$$

$$\sum_k y_{kl} = 1 \quad \text{for all } l \tag{3.5}$$

$$\sum_j x_{jk} \le z_k*M_k \quad \text{for all } k \tag{3.6}$$

$$x_{jk} \le y_{jk}*M_k \quad \text{for all } j,\ k \tag{3.7}$$

all variables are nonnegative

Where,

- j = cargo origin/supply point,
- k = aerial port of embarkation (transshipment),
- l = aerial port of debarkation (demand point),
- c_{jk} = weighted average cost per ton-mile of shipping from any origin j to any APOE k,
- c_{kl} = weighted average cost per ton-mile of shipping from any APOE k to any APOD l,
- d_{jk} = statute mile distance from origin j to APOE k,
- d_{kl} = nautical mile distance from APOE k to APOD l,
- v_j = APOE throughput cost per ton of cargo,
- x_{jk} = flow in tons per month of cargo shipped from origin j to APOE k,
- x_{kl} = flow in tons per month of cargo shipped from APOE k to APOD l
- f_k = monthly operating cost for APOE k
- z_k = a 0 - 1 variable; 1 if APOE is established at k, and 0 otherwise.

y_{kl} = a 0 - 1 variable; 1 if APOE k serves APOD l, and 0 otherwise,

S_j = origin supply limitation,

D_l = demand at APOD l, and

M_k = maximum OCONUS throughput of APOE k in tons per month.

The data requirements for the above formulation was inputted into a Microsoft Excel (21) spreadsheet and via a macro, output in a format for the CPLEX (22) linear programming package to solve. The formulation was then read into CPLEX.

Cargo Data

The analysis and breakdown of cargo demand data began with the FY96 TRAIS database. The shipments contained within this database are uniquely identified by a seventeen digit transportation control number (TCN). The TCN is a an alpha-numeric code used by the DOD in accordance with the Military Standards and Movement Procedures (MILSTAMP) to identify individual shipments within the DTS. The portion of the TRAIS database used for this study was updated on 27 February 1997 and stored on computer disk by AMC (4 and 5).

To facilitate extraction of useful information from TRAIS, it was necessary to obtain two other types of identification data. They were Department of Defense Activity Address Codes (DODAACs) and Air Terminal Identification Codes (ATICs). The DODAAC "is a six position alpha numeric code that identifies a unit, activity, or organization that has the authority to requisition and/or receive material from DOD." (23). The DODAAC is further separated into types of address codes (TACs): TAC 1, identifies a unit's mailing address; TAC 2, is a freight address; and TAC 3, is a billing address, which in many cases is at a location hundreds of miles away from the cargo delivery site. This separation initially caused problems accurately identifying cities of origin. The problem was resolved with the help of the organization responsible for maintaining the DODAAC database, the Defense Activity

Address System Center (DAASC) located at Wright-Patterson AFB, OH (21). ATIC codes were provided by AMC (5). An ATIC is the three-letter code identifying a unique airfield in the world.

The FY96 TRAIS is a very large database and for this analysis began with almost two million entries. Microsoft Access (22) database management system was used in conjunction with Microsoft Excel to manage the data. One quarter of cargo data was extracted from the original table, as this would be used to represent cargo movement for the year. Duplicate TCNs were then removed. The next step was to limit data to only the cargo that transited the six major APOEs of Charleston, Dover, McChord, McGuire, Norfolk, and Travis.

Linking the resultant table containing outbound cargo data with both the DODAAC information and ATIC table, queries were run to find the biggest shippers and ports of debarkation in the DTS served by the current APOEs. A consignor list by DODAAC was generated and the top origins were chosen to represent approximately 85 percent of the weight shipped through the six major APOEs. Consignors within the same or near cities were consolidated, as this should not significantly effect the final locations of the APOEs and it also served to reduce the complexity of the task. The number of destinations was also limited to the top APODs that represented approximately 85 percent of the weight delivered outside the CONUS via the six major APOEs. A couple of possible APOD sites were eliminated from the analysis based on blank identification locations within the TRAIS.

Matching consignor DODAACs with APODs and consolidating cities of origin, cargo movement information between these sites was generated and represented approximately 75 percent of the weight shipped through the APOEs. This new data was adjusted to equal 100 percent of the weight transiting the CONUS APOEs outbound. The new figures were then used as demand at particular APODs from specific origins, and that demand must be met in the linear program.

Distance Data

Distance between cargo origin points and APOEs were taken from the military regulation, Transportation and Travel Official Table of Distances (23). The tabled figures in this publication are based on driving distance and are statute miles.

Distances from CONUS APOEs to OCONUS APODs were for the most part obtained from a Borland Dbase IV database used at AMC (24). The database was converted from the Dbase IV to Microsoft Access format and appropriate distances in nautical miles were extracted. In some cases where no APOE-APOD match was shown, it was necessary to use the great circle equation to calculate distances. The formula listed below is from an Air Force air navigation manual:

$$D = 60\cos^{-1}[\sin(lat_1)\sin(lat_2) + \cos(lat_1)\cos(lat_2)\cos(long_2 - long_1)] \quad (3.8)$$

The lat and long represent the latitude and longitude, respectively, and degrees must be converted to radians in order to use this formula. The distance, D, is in nautical miles (nm) (25).

Cost Data

For CONUS truck transportation costs, an average ton-mile rate was obtained using the Military Traffic Management Command's (MTMC) Draft "Traffic Management Progress Report" (TMPR) for FY95 (26). FY95 data was used because it is from the most current report available. Also, as per notes on the TMPR, seven months of data was unrecoverable and was not used in MTMC's calculation of costs.

The percentage of shipments in the truckload (TL) (10,000 pounds and over) and less-than-truckload (LTL) (less than 10,000 pounds) categories were determined. These percentages were used along with the average ton-mile rate per weight-break to calculate a weighted average cost per ton-mile.

For air cargo transportation costs, Defense Business Operations Fund - Transportation (DBOF-T) airlift rates were taken from the "US Government Department of Defense (DOD) Rate Tariffs" appendix of the DBOF-T rate guide (27). The rates are broken down into five weight-breaks and are listed as dollars per pound-mile. These rates were converted into dollars per ton-mile and then a weighted rate per ton-mile was calculated. The breakdown of the percentage of shipments in each weight-break category was performed by AMC's Cargo Movement Branch using the FY96 TRAIS database (28).

Aerial port operating costs were obtained from AMC's, Financial Management and Budget Directorate (HQ AMC/FMBT). The costs include FY96 operating costs on file for the six major ports and "approximately $1.2 million related to maintenance and repair at these aerial ports. There are no military costs [personnel] included in these numbers"(29). Because this thesis was to examine alternative basing locations for the CONUS APOEs, the operating costs for the three inland port sites are not known. Therefore random numbers between the highest and lowest operating costs of the known APOEs were generated and used for the three additional inland port sites.

Summary

The demand data with the restricted set of locations, along with the distance and cost information just discussed, will be applied to the modified distribution center location model. This model most closely matches the current setup of the aerial port system and should provide some insight into the problem. The results from the application of the aforementioned methodology will be discussed in Chapter IV.

IV. Results

This chapter will present the findings as discovered by the application of the methods discussed in Chapter III. The research questions of Chapter I will form the heart of the results. Restated, they are:

1. Based on a modified distribution system location problem, what are the optimal locations and how many aerial port facilities are needed?
2. How does the new structure compare with the current APOE structure on a cost basis?

Cargo Data Analysis

As stated in the methodology, the original cargo data provided by AMC was the FY96 TRAIS database containing 1,916,541 line entries, with identifying transportation control numbers and other accompanying information. Although the TRAIS database was last updated on 27 February 1997, entries can still be deleted or added by AMC until an official close-out date is established. As of August 1997, one had not yet been set (4). The data is therefore not as accurate as it could be, but that should have little if any impact on the results of this analysis.

The breakdown of cargo began with the use of Microsoft Access to limit the large volume of data to a representative set of one quarter of FY96. That quarter was arbitrarily chosen to run from 1 April to 30 June 1996. This reduced the number of entries to 484,704, or as expected to approximately 25 percent. Next, in order to avoid duplicate information and provide channel summary data, line entries with duplicate TCNs were removed. This again resulted in a substantial reduction in the set under study to 374,791, or about 77 percent of that quarter's information.

One of the stipulations of this aerial port analysis was to move the same tonnage of cargo that transited the six major APOEs for overseas delivery. Therefore the cargo data set was further restricted to those shipments that originated within the CONUS and transited the six major APOEs destined for overseas APODs. Those APOEs again are Charleston AFB, SC, Dover AFB, DE, Norfolk NAS, VA, McChord AFB, WA, McGuire AFB, NJ, and Travis AFB, CA. This left the total number of line entries at 212,197.

Using the relational database capabilities of Microsoft Access, the table containing the 212,197 entries was linked with both the revised DODAAC table and the ATIC table. Queries were then run to find the biggest shippers and ports of debarkation by weight. The first query resulted in a consignor list of 12,136 entries separated by service, APOE, APOD, and city. The next consolidation of data was accomplished by summing all of the cargo originating from the same consignor. The list was again queried to show the top consignors by DODAAC, and the top 93 are shown in Appendix A. The cargo generated by these origins represent

84.61 percent of the weight shipped out of the CONUS through the six major APOEs. The one-quarter tonnage shipped through these ports was 23,614 for a monthly average of 7,871 tons. Those 93 origins were consolidated based on their proximity to one another and the resulting list was reduced to the 53 shown by city and state in Table 1.

The aerial ports of debarkation are shown in Appendix B, with the top 22 shown here in Table 2. The top 22 APODs represent 88.77 percent of the total cargo weight delivered outside the continental US that transited the six major APOEs.

Cross referencing the top 53 cities of origin with the top 22 APODs using Access, resulted in the extraction of 75.07 percent of the cargo which originated within the CONUS and was shipped overseas via the major APOEs. This cargo information by weight is shown in Appendix C. In order to put a more accurate load into the model of the aerial port system, the 75 percent tonnage figures were increased to equal 100 percent of the cargo originating within the CONUS that was shipped overseas via the major ports. The nodes were not changed but the shipping weights were modified.

Distance Data

The statute miles between cities of origin and APOEs, taken from the Transportation and Travel Official Table of Distances, are shown in Table 3. For those locations not included in the regulation, it was necessary to obtain the distance to a nearby city and manually adjust the mileage.

Nautical miles between APOEs and APODs, as taken from an AMC table of distances, are shown in Table 4.

Table 1. Top Cities of Origin.
(1 April - 30 June 1996)

	CITY OF ORIGIN	STATE	WEIGHT (lbs.)	SHIPMENTS
1	Anniston	AL	308,933	288
2	Ft Rucker	AL	182,473	236
3	Huntsville	AL	93,946	78
4	Ft Huachuca	AZ	114,279	241
6	Lathrop	CA	2,441,370	21,960
7	Lemoore NAS	CA	84,201	282
8	McClellan AFB	CA	717,128	3,859
9	Monterrey	CA	141,391	117
5	Oakland	CA	565,434	1,663
10	San Diego	CA	794,713	4,952
11	Travis AFB	CA	1,793,062	2,205
12	Peterson AFB	CO	102,938	242
27	Washington	DC	746,117	1,065
13	Dover AFB	DE	2,420,973	4,718
14	Eglin AFB	FL	358,817	761
15	Jacksonville	FL	114,313	268
16	Orlando	FL	810,778	2,450
17	Ft Benning	GA	135,608	267
19	Ft Stewart	GA	180,196	386
18	Palmetto	GA	257,477	818
20	Robins AFB	GA	271,670	276
21	Chicago	IL	158,156	99
22	Rock Island	IL	256,736	124
23	Scott AFB	IL	79,037	160
24	Crane	IN	260,601	175
25	Ft Campbell	KY	130,099	328
26	Ft Knox	KY	81,383	166
28	Kessler AFB	MS	99,325	212
29	Malmstrom	MT	71,730	68
30	Camp Lejuene	NC	189,144	339
31	Ft Bragg	NC	286,984	648
32	Offutt AFB	NE	91,313	131
34	McGuire AFB	NJ	1,987,133	3,662
35	Nellis AFB	NV	97,741	222
33	New York	NY	183,029	93
36	Columbus	OH	144,464	6,499
37	Tinker AFB	OK	377,168	2,078
38	New Cumberland	PA	12,831,930	54,313
39	Philadelphia	PA	196,056	1,132
40	Tobyhanna	PA	469,437	1,252
41	Charleston	SC	1,244,857	1,219
42	Shaw AFB	SC	130,678	305
43	Memphis	TN	334,053	3,814
44	Corpus Christi	TX	112,748	696
45	Fort Worth	TX	592,005	964
46	Ft Hood	TX	143,238	349
47	San Antonio	TX	607,352	2,606
48	Texarkana	TX	308,530	929
49	Hill AFB	UT	781,398	5,940
51	Norfolk	VA	3,192,288	13,522
50	Richmond	VA	1,052,708	13,557
52	McChord AFB	WA	756,699	859
53	Oak Harbor	WA	75,883	210
			WEIGHT (lbs.)	SHIPMENTS
		TOTAL	39,959,720	163,803

Table 2. Top Aerial Ports of Debarkation.
(1 April - 30 June 1996)

	APOD/ATIC	CITY	COUNTRY	WEIGHT (lbs.)	SHIPMENTS
1	RMS	RAMSTEIN AB	GERMANY	15,698,706	36,528
2	OSN	OSAN AB	SOUTH, KOREA	3,681,797	8,986
3	HIK	HONOLULU	UNITED STATES	2,183,901	10,408
4	OKO	TOKYO	JAPAN	2,113,672	15,206
5	KWI	KUWAIT CITY	KUWAIT	1,945,244	1,269
6	HOW	HOWARD AB	PANAMA	1,567,047	5,636
7	DHA	DHAHRAN	SAUDI ARABIA	1,452,686	11,102
8	DNA	KADENA AB	JAPAN	1,261,717	10,369
9	SIZ	SIGONELLA AB	ITALY	1,180,224	15,192
10	MHZ	MILDENHALL AB	UNITED KINGDOM	1,060,807	9,645
11	KEF	KEFLAVIK	ICELAND	1,033,173	3,681
12	BAH	BAHRAIN	BAHRAIN	992,246	7,851
13	NBW	GUANTANAMO BAY	CUBA	737,502	1,494
14	NRR	ROOSEVELT ROADS	PUERTO RICO	726,723	3,509
15	UAM	ANDERSON AFB	GUAM	629,812	6,112
16	THU	THULE AB	GREENLAND	579,544	1,194
17	RTA	ROTA (NAS)	SPAIN	504,899	5,657
18	EDF	ANCHORAGE	UNITED STATES	472,560	1,992
19	RUH	RIYADH	SAUDI ARABIA	432,963	3,728
20	KWA	KWAJALEIN	US TERRITORY	398,640	474
21	PLA	PALMEROLA	HONDURAS	389,241	415
22	ASP	ALICE SPRINGS	AUSTRALIA	378,266	131
				WEIGHT	**SHIPMENTS**
			TOTAL	**39,421,370**	**160,579**

Those origin-destination pairs not listed in AMC's mileage table were calculated from the great circle equation (3.8) and are shown with an asterisk.

Table 3. Origin to APOE Distance

	Origin	CHS	DOV	HIF	NGU	TCM	WRI	SUU	TIK	FFO
		APOE								
1	Anniston AL	375	813	1850	662	2605	879	2392	750	547
2	Palmetto GA	304	738	1923	587	2678	804	2488	846	558
3	Benning Ft GA	379	840	1957	689	2712	906	2492	857	657
4	Bragg Ft NC	206	426	2162	242	2854	496	2814	1172	552
5	Campbell Ft KY	587	817	1611	733	2366	880	2303	661	346
6	Charleston SC	10	603	2203	416	2955	675	2768	1126	697
7	Chicago IL	907	779	1406	877	2042	778	2111	795	286
8	Columbus OH	658	505	1699	583	2356	504	2404	937	67
9	Corpus Christi TX	1292	1725	1507	1590	2332	1788	1876	594	1334
10	Crane IN	644	659	1476	697	2221	581	2183	687	208
11	Dover AFB DE	609	10	2162	198	2819	111	2867	1417	569
12	Eglin AFB FL	506	1036	1980	883	2786	1102	2444	877	767
13	Fort Worth TX	1099	1455	1253	1371	2078	1518	1717	210	1024
14	Harrisburg	621	146	2028	294	2685	134	2733	1305	236
15	Hill AFB UT	2195	2162	10	2227	825	2161	723	1152	1615
16	Hood Ft TX	1169	1572	1306	1448	2121	1635	1748	354	1141
17	Huachuca Ft AZ	1983	2334	874	2250	1593	2358	939	930	1795
18	Huntsville AL	470	804	1767	710	2522	867	2309	667	447
19	Jacksonville FL	262	826	2221	627	2976	885	2734	1124	867
20	Kessler AFB MS	655	1116	1852	965	2671	1182	2316	749	835
21	Knox Ft KY	641	733	1638	669	2369	736	2337	791	192
22	Lejuene Camp NC	234	389	2288	202	2976	479	2936	130	674
23	Lemoore NAS CA	2758	2877	833	2793	919	2887	209	1452	2324
24	Malmstrom MT	2279	2151	553	2249	668	2150	1120	1402	1658
25	McChord AFB WA	2947	2819	825	2917	10	2818	724	1968	2326
26	McClellan AFB CA	2759	2815	671	2880	721	2814	54	1641	2306
27	McGuire AFB NJ	680	111	2161	288	2818	10	2866	1438	568
28	Memphis TN	665	964	1553	880	2308	1027	2095	453	533
29	Nellis AFB NV	2256	2510	436	2471	1127	2509	569	1138	1964
30	New York NY	735	166	2180	346	2828	69	2885	1473	603
31	Norfolk VA	422	198	2227	10	2917	288	2932	1333	617
32	Oakland CA	2752	2911	767	2965	768	2910	47	1632	2402
33	Offutt AFB NE	1288	1235	930	1300	1680	1234	1635	447	726
34	Ord Ft CA	2719	3014	880	2926	874	3013	153	1593	2465
35	Orlando FL	392	956	2334	769	3093	1027	2828	1234	988
36	Peterson AFB CO	1676	1762	580	1729	1396	1761	1269	606	1198
37	Philadelphia PA	650	81	2133	271	2790	34	2838	1410	540
38	Richmond VA	405	205	2139	88	2829	275	2844	1256	529
39	Robins AFB GA	292	791	2006	624	2761	857	2571	929	641
40	Rock Island IL	1038	928	1240	1011	1940	927	1945	714	435
41	Rucker Ft AL	439	960	1968	801	2722	1026	2477	875	702
42	San Antonio TX	1266	1693	1356	1576	2181	1756	1725	481	1262
43	San Diego CA	2410	2761	775	2677	1217	2785	509	1357	2222
44	Scott AFB IL	827	923	1376	880	2131	922	2075	529	370
45	Shaw AFB SC	107	558	2137	371	2884	629	2729	1087	626
46	Stewart Ft GA	154	718	2148	523	2902	789	2712	1078	739
47	Lathrop CA	2708	2868	724	2923	762	2867	52	1590	2359
48	Red River TX	925	1259	1395	1169	2222	1322	1861	288	828
49	Tinker AFB OK	1118	1417	1152	1333	1968	1438	1642	10	875
50	Tobyhanna PA	744	184	2101	371	2748	126	2805	1414	546
51	Travis AFB CA	2760	2867	723	2932	724	2866	10	1642	2358
52	Washington D.C.	512	103	2072	191	2728	169	2776	1314	478
53	Whidbey Island WA	2985	2857	862	2955	108	2856	824	2007	2364

Source: AFR 177-135 Transportation and Travel Official Table of Distances. Distances are in statute miles. CHS-Charleston AFB SC, DOV-Dover AFB DE, HIF-Hill AFB UT, NGU-Norfolk NAS VA, TCM-McChord AFB WA, WRI-McGuire AFB NJ, SUU-Travis AFB CA, TIK-Tinker AFB OK, FFO- Wright-Patterson AFB OH.

Table 4. APOE to APOD Distance.

	APOD	APOE								
		CHS	DOV	HILL	NGU	TCM	WRI	SUU	TIK	FFO
1	ASP	8947	*9063	*7413	9070	6977	*9078	7585	*8083	*8672
2	BAH	6340	6391	6659	6291	6396	5948	8593	6695	*6107
3	DHA	6268	5955	6653	6092	6393	5890	7395	6893	6097
4	DNA	7367	6797	5581	6784	5003	7495	5309	6318	6466
5	EDF	3369	2958	1827	3040	1266	3363	1799	2506	2679
6	HIK	4173	4274	2606	4265	2310	4301	2115	3262	3874
7	HOW	1641	1868	2582	1892	3162	1880	3492	2310	1864
8	KEF	2806	2371	3222	2503	4402	2305	4491	3421	2562
9	KWA	*6236	6400	4626	6298	4774	*6318	4241	5388	*5916
10	KWI	6059	6167	6451	5757	6419	5573	7798	7195	5885
11	MHZ	3552	3134	4203	3856	5166	3069	5244	4032	3402
12	NBW	820	1158	*2262	1021	*2823	1826	3383	2201	1196
13	NRR	1171	1389	2738	1252	3266	1672	3229	3297	*1605
14	OKO	7070	5978	4763	6115	4184	6676	4490	5499	5688
15	OSN	7149	6579	5116	6191	4785	7277	5091	6100	5896
16	PLA	1195	1614	2074	1479	2623	1680	2314	1364	1533
17	RMS	3938	3449	4519	3564	5494	3384	4914	4355	3722
18	RTA	3556	3500	4617	3288	4732	3148	5614	4750	3557
19	RUH	6581	5800	6693	5914	6466	6099	8820	7192	6066
20	SIZ	4577	4446	*5250	4309	6253	4194	5720	5218	4388
21	THU	2702	2276	2400	2389	4298	2201	4387	3317	2244
22	UAM	7468	8992	5451	6993	5544	7596	5410	6557	6605

Source: AMC Mileage Table (Borland Dbase IV File converted to Microsoft Access 95). Distances are in nautical miles. Note: *From the great circle equation. For APOE abbreviations see Table 3.
ASP-Alice Springs Australia, DAH-Dhahran Saudi Arabia, DNA-Kadena AB Japan, EDF-Elmendorf AFB AK, HIK-Hickam AFB HI HOW-Howard AFB Panama, KEF-Keflavik Iceland, KWA-Kwajalein Marshall Island, KWI-Kuwait City Kuwait, MHZ-Mildenhall AFB England, NBW-Guantanamo Bay Cuba, NRR-Roosevelt Roads NAS Puerto Rico, OKO-Yokota AFB Japan, OSN-Osan AB Korea, PLA-Soto Cano Honduras, RMS-Ramstein AB Germany, RTA-Rota NAS Spain, RUH-Riyadh Saudi Arabia, SIZ-Sigonella Italy, THU-Thule AB Greenland, UAM-Andersen AFB Guam.

Cost Data

The inland truck freight transportation costs obtained from MTMC's "Traffic Management Progress Report" are shown in Table 5. The resultant weighted average cost was 0.2799 dollars per ton-mile. This was used as a linear transportation cost function for shipping from city of origin to aerial port of embarkation.

Table 5. Ton-mile Costs for Inland Freight Traffic.

	Shipments (000)	Percent	Average Cost/Ton-mile	Weighted Average Cost/Ton-mile
TL 10,000 lbs and over	86.85	19.03	$0.0907	
LTL Less than 10,000 lbs	369.54	80.97	$0.3244	
Total	456.39	100.00		**$0.2799**

Source: MTMC's Traffic Manangement Progress Report (Draft) for FY95.
Data from March-September excluded due to reporting deficiencies.

Air transportation costs are also dependent on the weight break category that a shipment falls into. The AMC weight breaks used in this problem were for FY96 and are shown in Table 6. Also shown are the percentage of shipments within each weight break. One can see that the majority of the shipments, approximately 81 percent, are in the smallest category of 1 to 439 pounds. This information

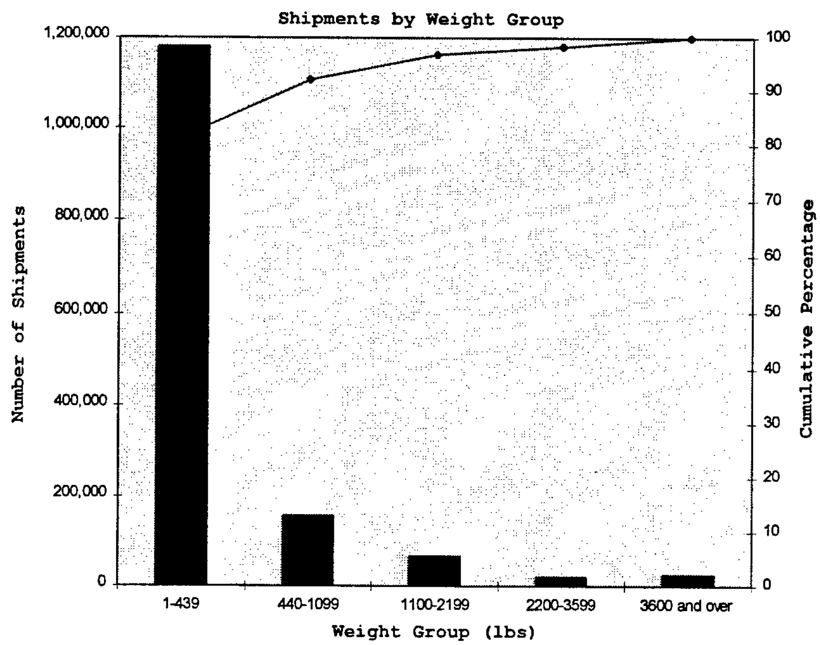
Table 6. AMC Channel Weight Breaks and Costs

Shipment Size (lbs)	Percent	Rate Cost/Ton-mile	Weighted Average Cost/Ton-mile
1-439	81.46	$1.0162956000	
440-1099	10.75	$0.9139566000	
1100-2199	4.54	$0.8139292000	
2200-3599	1.48	$0.7103598000	
3600 and over	1.77	$0.6254112000	
TOTAL	100		$0.9846602192

Source: US Government - DBOF-T Airlift Rate Guide FY96.

is again shown in Figure 1 and can be used to calculate a weighted average of air transportation cost. The resulting value of 0.9845 dollars per ton-mile was used in this application.

Figure 1. Shipments within Channel Weight Breaks



Source: HQ/AMC/DONCM; FY96 World-Wide Channel Shipment Profile Study

Aerial port operating costs obtained from HQ AMC/FMBT, are shown in Table 7. Values drawn randomly from the uniform distribution formed by the highest and lowest port operating costs at Travis and McChord were used as operating costs for the three inland bases of Hill, Tinker, and Wright-Patterson.

Table 7. Aerial Port Operating Costs (FY96).

APOE	Operating Cost (000)
Charleston AFB SC	$6,510.70
Dover AFB DE	$7,833.20
McChord AFB WA	$4,785.70
McGuire AFB NJ	$4,829.10
Norfolk NAS VA	$7,679.50
Travis AFB CA	$9,067.90
Hill AFB UT	$7,706.60
Tinker AFB OK	$4,960.60
Wright-Patterson AFB OH	$6,613.70

Source: HQAMC/FMBT. Note: Hill, Tinker, and Wright-Patterson costs randomly generated from uniform distribution.

Port Capacities

CONUS aerial port throughput capacities shown in Table 8, are all based on the current manpower authorized (except Hill, Tinker, and Wright-Patterson) at those locations. That is to say that if manning was increased during peacetime, the throughput capability would also increase. Also, high manning levels is not a cure all. Other factors such as material handling equipment, ramp space, storage facilities, and fuel, can also and do limit the capacity of aerial ports. The results of this study must be carefully examined and weighed against other pertinent variables before any final decisions are made on the future of the aerial ports of embarkation (30 and 31).

The total throughput capacity figures obtained from AMC are shown in Table 8. They represent the amount of cargo in tons per month that transit these aerial ports both for CONUS delivery and OCONUS delivery. Because this thesis is concerned with the placement of CONUS APOEs not APODs, the total capacity of these ports had to be adjusted. That adjustment, results shown in Table 8, is a first attempt to capture that portion of a port's capacity that is consumed by the outward movement of cargo.

As with port costs, capacities of the three inland bases were not available but had to be derived. Drawing randomly from a uniform distribution gave the results in Table 8 for Hill, Tinker, and Wright-Patterson.

Table 8. Aerial Port Throughput Capacities

	Conus Aerial Port	% as APOE	Total Throughput Capacity (tons/month)	OCONUS Throughput Capacity (tons/month)
1	Charleston AFB SC	70.60%	5,500	3,883
2	Dover AFB DE	67.86%	9,500	6,447
3	Norfolk NAS VA	66.78%	6,000	4,007
4	McChord AFB WA	67.81%	1,500	1,017
5	McGuire AFB NJ	81.08%	2,000	1,622
6	Travis AFB CA	58.26%	8,500	4,952
7	Hill AFB UT			**4583**
8	Tinker AFB OK			**4363**
9	Wright-Patterson AFB OH			**3264**

Source: HQ AMC/DOZX and AMC Air Terminal Norfolk NAS.
Hill, Tinker, and Wright-Patterson random from uniform distribution.

Old vs. New Port Structure

The detailed data discussed throughout this chapter was inputted into the revised formulation of a distribution problem. The macro written by Maj Ray Hill which creates a CPLEX readable file, is shown in Appendix D (32). The results of the subroutines, those being the objective function and constraints of the linear program fed into the CPLEX Linear Optimizer, can be provided by the author on request. This is also true for the large output file from CPLEX.

The first run of the formulation indicates that three CONUS aerial port facilities should remain open, two on the East coast and one on the West. They are the ports at Dover AFB, DE, McGuire AFB, NJ, and Travis AFB, CA. The total cost calculated for that system was 33.41 million dollars with the APOEs sharing the monthly workload as follows: Dover - 4,212 tons, McGuire - 1,622 tons, and Travis - 2,036 tons. The total cost includes CONUS freight, air freight, and port operating costs. Naturally, Travis was entirely focused on destinations west and Dover and McGuire to the east. Upon examination of the results, one notices that McGuire has hit its capacity limitation. This would lead one to conclude that the LP opened McGuire first because McGuire had the least expensive operating cost. McGuire being quickly overwhelmed with cargo, lead to the opening of Dover. Intuitively one would say that Dover should be the only east coast port, as it dwarfs the capacity of McGuire, could handle all eastbound cargo, and would surely limit the overall system cost if McGuire were closed.

In order to test the above theory, the LP was again solved, only this time Dover was forced to open first. The answer returned was not what was expected. Dover, Travis, and McGuire all remained open, with no decrease in overall cost. To take it one step further and check the validity of the LP, Dover was again forced open but this time McGuire was forced closed. In that case only Dover and Travis had the active aerial ports, but overall cost increased. Although a relatively minor adjustment of about 49,000 dollars, the increase was not expected. With 5,834 tons and 2,036 tons transiting Dover and Travis respectively, the system cost increased to 33.46 million dollars.

The decision to restructure the APOE system will and should be based on many factors. For this thesis, the key factor of comparison between the current and new structure is cost. Those are port operating and transportation costs, both CONUS truck freight, and overseas air freight. The current APOE structure was compared with the model output based on the cargo data set used for this thesis. That would include 7,871 tons per month, port operating costs provided by AMC/FMBT, 0.2799 dollars per ton-mile for CONUS freight, and 0.9845 dollars per ton-mile for air freight.

The current DTS structure contains the six coastal aerial port facilities of Charleston, Dover, McChord, McGuire, Norfolk, and Travis. Using the above comparison factors, a rough cost estimate was obtained for today's system. Those costs are listed in Table 9. Also shown is the total cost of the three-port structure. The difference in monthly cost of the two systems is 960 thousand dollars per month for an annual figure of 11.5 million dollars

Table 9. Old vs. New APOE Structure - Cost Comparison

	System	
Cost/Month	**Six-Port**	**Three-Port**
Total Freight	$30,979,421	$31,600,480
Operating	$3,392,175	$1,810,850
TOTAL	$34,371,596	$33,411,330

Summary

Applying the methodology from Chapter III led to answers to the basic questions of this research effort. Those were:

1. What are the optimal locations and how many aerial port facilities are needed?

2. How does the new structure compare with the current APOE structure on the basis of cost?

By analyzing the flow of cargo from CONUS origination sites, to aerial ports of debarkation, the data points input into the model were reduced to a easily manageable number. The final cut represented over 75 percent of the total flow of cargo through the APOEs. Distances, costs, and capacities were obtained from official sources and when necessary derived. This string of data was then input into the modified multicommodity distribution formulation of Geoffrion and Graves, leading to the recommendation to only keep the three APOEs of Travis, Dover, and McGuire open.

The model portrays an approximate one million dollar saving if the new structure replaces the current one. Some of the other factors influencing the location of aerial ports will be briefly mentioned in conclusion.

V. Conclusion

With the continued reduction in force size and base structure, the US Armed Forces retreat more and more to the continental United States. Exacerbating the situation is the relentless budget cutting of Congress. As a result, the requirement for the current high level of material support provided to overseas locations is waning. The force restructuring to include the consolidation of distribution depots under one "roof" has forced another look at the aerial port system. More specifically where and how many CONUS aerial port facilities should the future Defense Transportation System have? Once that was determined, how does the cost of the new system compare to that of the old? That was the basic thrust of this thesis and answers to the above questions were obtained by modeling the APOE system as a transshipment problem.

This effort began with a review of the literature available dealing with facility location problems. Through extensive research, the focus was narrowed to one of two possible solution methods, or models. One, by Bhaskaran, was applied to an automobile manufacture's location of transshipment facilities between suppliers and final assembly plants. The multicommodity distribution system formulation of Geoffrion and Graves was the other possible model. It was determined that the multicommodity model could be modified to best represent the current aerial port system.

The result of this modified formulation was that three CONUS aerial port facilities should remain open, two in the East and one in the West. This port structure allows increased consolidation of cargo for air shipment and significantly reduces the total cost of shipment as defined in this problem. The savings stem from the operating cost reduction with the closure of the three APOEs of Charleston, McChord, and Norfolk.

There are a couple of other benefits in this three port solution than just cost. With the opening of three versus two ports (2 could handle the capacity) there is a greater surge capability built into the system. Of course it would not be as high as a six-port system would but the capability to handle any number of emergencies or contingencies is still there. With the overall cost of the system declining, AMC could move for a reduction in the price of air shipment for its DOD customers.

It must be realized that numerous assumptions and simplistic representations were made in order to reduce the complexity of the aerial port location study. The short list includes the following. The number of nodes, origins and APODs, were limited to only represent 75 percent of the tonnage transiting the six major APOEs. The demands in the model were deterministic and were exactly met, whereas in reality there is always some variability. The only port costs considered were operating costs. They did not include personnel and numerous other costs. Capacities used were derived based on the percentage of outbound cargo a port handles. This short list plus other limiting factors omitted, such as storage capacity, ramp space, fuel, cargo handling equipment, and other support activities, must be examined carefully before any closure actions are taken. Major areas not addressed in this research also include aircraft inventory and basing strategies and route timing and location. These may have an impact on CONUS port locations, and would definitely need to be addressed in a larger more comprehensive study of the whole distribution system.

Appendix A: Top Consignor DODAACs.
(1 April - 30 June 1997)

	CONSIGNOR	CITY	STATE	WEIGHT (lbs.)	SHIPMENTS
1	SW3123	New Cumberland	PA	10,898,222	3,372
2	FB4497	Dover AFB	DE	2,420,973	4,718
3	FB4427	Travis AFB	CA	1,793,062	2,205
4	FB4484	McGuire AFB	NJ	1,407,893	1,079
5	SW3225	Lathrop	CA	1,224,345	2,007
6	FB4418	Charleston	SC	1,058,155	910
7	SW3100	Mechanicsburg	PA	1,029,246	24,264
8	SB3106	Norfolk	VA	982,940	1,221
9	SW3124	New Cumberland	PA	904,462	26,677
10	SW0400	Richmond	VA	875,600	12,092
11	S1002A	Orlando	FL	810,778	2,450
12	SW3200	Tracy	CA	611,161	11,892
13	FB4479	McChord AFB	WA	577,747	246
14	SW3400	Ogden	UT	564,546	3,919
15	W73BFY	Arlington	VA	531,131	713
16	N00189	Norfolk	VA	487,944	2,039
17	GN0003	Burlington	NJ	465,528	2,516
18	SW3224	Lathrop	CA	462,378	7,255
19	SW3213	Kelly AFB	TX	457,757	2,552
20	SW3117	Norfolk	VA	456,967	7,143
21	FX2072	McClellan AFB	CA	401,924	150
22	SW3211	Tinker AFB	OK	377,168	2,078
23	SW3218	San Diego	CA	361,681	3,484
24	SW3114	Tobyhanna	PA	355,286	1,061
25	HX7NNW	Newport News	VA	354,862	722
26	SW3500	Memphis	TN	334,053	3,814
27	N00188	Norfolk	VA	323,818	789
28	SW3212	McClellan AFB	CA	315,204	3,709
29	SW3227	Texarkana	TX	308,530	929
30	N00244	San Diego	CA	295,772	1,306
31	W36R4X	Ft Bragg	NC	286,984	648
32	FX2399	Robins AFB	GA	271,670	276
33	HM0093	Mineral Wells	TX	268,536	129
34	W53XMD	Crane	IN	260,601	175
35	SCGA08	Union City	CA	258,410	229
36	W52H1C	Rock Island	IL	256,736	124
37	HXYAAA	Dallas	TX	247,963	341
38	SW3210	Hill AFB	UT	216,852	2,021
39	FB4800	Langley AFB	VA	204,656	702
40	M31000	Camp Lejuene	NC	189,144	339
41	GA0001	Palmetto	GA	185,098	681
42	N65580	Portsmouth	VA	183,114	329

43	W31R4Z	Ft Rucker	AL	182,473	236
44	W33GGZ	Ft Stewart	GA	180,196	386
45	W31G1Z	Anniston	AL	160,509	129
46	FB2823	Eglin AFB	FL	158,219	362
47	S1403A	Chicago	IL	158,156	99
48	S4404A	San Antonio	TX	149,595	54
49	SW3120	Anniston	AL	148,424	159
50	SW0700	Columbus	OH	144,464	6,499
51	GS0001	Stockton	CA	143,486	806
52	W45QRE	Ft Hood	TX	143,238	349
53	W62R65	Monterrey	CA	141,391	117
54	N66001	San Diego	CA	137,260	162
55	W33APT	Ft Benning	GA	135,608	267
56	FB4803	Shaw AFB	SC	130,678	305
57	W34GNA	Ft Campbell	KY	130,099	328
58	N57012	Norfolk	VA	125,987	526
59	SP0200	Philadelphia	PA	117,907	1,075
60	FB4819	Tyndall AFB	FL	117,374	205
61	W23A9F	Ft Meade	MD	115,670	222
62	N68836	Jacksonville	FL	114,313	268
63	W61DEL	Ft Huachuca	AZ	114,279	241
64	W25G1W	Tobyhanna	PA	114,151	191
65	N60478	Colts Neck	NJ	113,712	67
66	SW3222	Corpus Christi	TX	112,748	696
67	N00228	Alameda	CA	108,233	232
68	GN0SDD	New York	NY	108,109	83
69	W68P4L	Ft Lewis	WA	107,829	227
70	SP0400	Richmond	VA	104,958	1,298
71	FB2500	Peterson AFB	CO	102,938	242
72	N65236	North Charleston	SC	101,766	226
73	CL0KX3	Oakland	CA	99,517	109
74	FB3010	Kessler AFB	MS	99,325	212
75	S2101A	Towson	MD	99,316	130
76	N44399	Oakland	CA	99,274	1,093
77	FB4852	Nellis AFB	NV	97,741	222
78	W31P38	Huntsville	AL	93,946	78
79	FB4600	Offutt AFB	NE	91,313	131
80	N39825	Goose Creek	SC	84,936	83
81	N63042	Lemoore NAS	CA	84,201	282
82	N00204	Pensacola	FL	83,224	194
83	W22PL1	Ft Knox	KY	81,383	166
84	FB4407	Scott AFB	IL	79,037	160
85	HM0016	Philadelphia	PA	78,149	57
86	N00620	Oak Harbor	WA	75,883	210
87	GF0001	Fort Worth	TX	75,506	494
88	W15QLN	Bayonne	NJ	74,920	10
89	W33FRS	Ft Gillem	GA	72,379	137
90	W26HBK	Ft Lee	VA	72,150	167

91	N00109	Yorktown	VA	72,000	51
92	FB4626	Malmstrom	MT	71,730	68
93	SW3216	Bremerton	WA	71,123	386
		TOTAL		**WEIGHT (lbs.)**	**SHIPMENTS**
		Top 93		39,959,720	163,803
			tons	19,980	
		System		47,228,046	184,200
			tons	23,614	
		PERCENT		84.61	88.93

Appendix B: Aerial Ports of Debarkation
(1 April - 30 June 1997)

	APOD/ATIC	CITY	COUNTRY	WEIGHT (lbs.)	SHIPMENTS
1	RMS	RAMSTEIN	GERMANY	15,698,706	36,528
2	OSN	OSAN	KOREA SOU	3,681,797	8,986
3	HIK	HONOLULU	UNITED ST	2,183,901	10,408
4	OKO	TOKYO	JAPAN	2,113,672	15,206
5	KWI	KUWAIT	KUWAIT	1,945,244	1,269
6	HOW	HOWARD	PANAMA	1,567,047	5,636
7	DHA	DHAHRAN	SAUDI ARA	1,452,686	11,102
8	DNA	KADENA	JAPAN	1,261,717	10,369
9	SIZ	SIGONELLA	ITALY	1,180,224	15,192
10	MHZ	MILDENHALL	UNITED KI	1,060,807	9,645
11	KEF	KEFLAVIK	ICELAND	1,033,173	3,681
12	BAH	BAHRAIN	BAHRAIN	992,246	7,851
13	NBW	GUANTANAMO	CUBA	737,502	1,494
14	NRR	ROOSEVELT ROADS	PUERTO RICO	726,723	3,509
15	UAM	ANDERSON AFB	GUAM	629,812	6,112
16	THU	THULE AIR BASE	GREENLAND	579,544	1,194
17	RTA	ROTA (NAS)	SPAIN	504,899	5,657
18	EDF	ANCHORAGE	UNITED ST	472,560	1,992
19	RUH	RIYADH	SAUDI ARA	432,963	3,728
20	KWA	KWAJALEIN	TRUST TER	398,640	474
21	PLA	PALMEROLA	HONDURAS	389,241	415
22	ASP	ALICE SPRINGS	AUSTRALIA	378,266	131
23	PAP	PORT AU PRINCE	HAITI	274,966	521
24	TZL	TUZLA	BOSNIA-HE	258,529	405
25	MSJ	MISAWA	JAPAN	243,966	1,746
26	EIL	FAIRBANKS	UNITED ST	224,657	746
27	LPB	LA PAZ	BOLIVIA	215,073	440
28	LGS	LAJES	PORTUGAL	191,941	659
29	ADA	ADANA	TURKEY	190,497	594
30	UIO	QUITO	ECUADOR	184,008	91
31	NKW	DIEGO GARCIA (SEE/VO	BR. IND.	164,186	1,184
32	TTH	THUMRAIT	OMAN	150,224	2,567
33	SAL	SAN SALVADOR	EL SALVAD	144,976	277
34	JON	JOHNSTON ATOLL	JOHNSTON	142,051	236
35	FUK	FUKUOKA	JAPAN	120,975	1,141
36	TLV	TEL AVIV	ISRAEL	114,005	252
37	RCM	RICHMOND	AUSTRALIA	112,744	274
38	ADH	ALDAN	RUSSIAN F	111,705	47
39	MIQ	CARACAS (NOT IATA; S	VENEZUELA	105,112	95
40	SGP	SINGAPORE	SINGAPORE	96,553	2,141
41	BKK	BANGKOK	THAILAND	90,748	46
42	DKR	DAKAR	SENEGAL	89,438	25

43	NBO	NAIROBI	KENYA	83,643	148
44	KUZ	KUNSAN	KOREA SOU	82,960	1,261
45	NAP	NAPLES	ITALY	81,784	689
46	FUJ	FUKUE	JAPAN	77,707	611
47	IWA	IWAKUNI	JAPAN	75,103	1,560
48	OZP	SEVILLA	SPAIN	71,129	24
49	AVB	AVIANO	ITALY	70,542	586
50	AWK	WAKE ISLAND	WAKE ISLA	63,979	76
51	UTP	RAYONG	THAILAND	59,378	112
52	TZR	TASZAR	HUNGARY	58,894	225
53	TIF	TAIF	SAUDI ARA	53,483	138
54	LIM	LIMA-CALLOA	PERU	51,480	381
55	BOG	BOGOTA	COLUMBIA	50,833	149
56	TGU	TEGUCIGALPA	HONDURAS	48,507	94
57	AKT	AKROTIRI	CYPRUS	48,374	91
58	UMR	WOOMERA	AUSTRALIA	46,025	82
59	KHE	KIMHAE	KOREA SOU	42,191	870
60	GUA	GUATEMALA CITY	GUATEMALA	33,681	42
61	RIO	RIO DE JANIERO	BRAZIL	33,500	26
62	STX	ST CROIX	VIRGIN IS	31,602	38
63	OLB	OLBIA	ITALY	29,895	235
64	BUE	BUENOS AIRES	ARGENTINA	29,824	47
65	SCL	SANTIAGO	CHILE	29,079	31
66	BSB	BRASILIA	BRAZIL	28,220	24
67	CAI	CAIRO	EGYPT	28,162	146
68	SOC	SOLO	INDONESIA	26,427	29
69	AMM	AMMAN	JORDAN	26,340	68
70	CHC	CHRISTCHURCH	NEW ZEALA	25,742	406
71	CUA	CUBI POINT BATAAN	PHILIPPIN	23,500	10
72	AJR	ARVIDSJAUR	SWEDEN	22,900	34
73	KPI	KAPIT	MALAYSIA	21,155	10
74	MGA	MANAGUA	NICARAGUA	20,492	16
75	OCO	SAN JOSE OCCIDENTAL	PHILIPPIN	19,074	28
76	MVD	MONTEVIDEO	URUGUAY	18,500	18
77	PSE	PONCE	PUERTO RI	18,430	8
78	FIH	KINSHASA	ZAIRE	18,324	11
79	NDJ	N'DJAMENA	CHAD	18,068	20
80	FNA	FREETOWN	SIERRA LE	17,200	4
81	KWJ	KWANGJU	KOREA SOU	16,565	193
82	DJK	JAKARTA	INDONESIA	15,918	10
83	ESB	ANKARA	TURKEY	13,535	26
84	DIY	DIYARBAKIR	TURKEY	13,143	212
85	PBM	PARAMARIBO	SURINAME	11,710	10
86	SQX	SHAHEED MWAFFAQ AB	JORDAN	11,510	90
87	TJS	TANJUNG SELOR	INDONESIA	10,530	2
88	BZE	BELIZE	BELIZE	9,880	9
89	YOD	COLD LAKE	CANADA	9,460	3
90	IGL	IZMIR	TURKEY	9,066	22

91	ADQ	KODIAK	UNITED ST	6,427	41
92	YHM	HAMILTON	CANADA	6,320	2
93	NIM	NIAMEY	NIGER	5,856	5
94	QIE	ISTRES	FRANCE	5,204	4
95	KIN	KINGSTON	JAMAICA	4,245	2
96	SGZ	SONGKHLA	THAILAND	3,126	9
97	SYA	SHEMYA	UNITED ST	2,940	8
98	GEO	GEORGETOWN	GUYANA	2,780	6
99	FRF	FRANKFURT	GERMANY	2,763	9
100	GPA	PATRAS	GREECE	2,382	5
101	SRI	SAMARINDA	INDONESIA	2,099	51
102	SKJ	SITKINAK ISLAND	UNITED ST	2,000	1
103	YQX	GANDER	CANADA	1,584	2
104	NAS	NEW PROVIDENCE ISLAN	BAHAMA IS	1,100	1
105	BRI	BARI	ITALY	1,019	5
106	SJJ	SARAJEVO	BOSNIA-HE	900	1
107	BRW	BARROW	UNITED ST	633	2
108	XMR	MARMANDE	FRANCE	600	3
109	BDS	BRINDISI	ITALY	485	13
110	KUL	KUALA LUMPUR INTL	MALAYSIA	391	1
111	YES	ISTANBUL	TURKEY	352	3
112	DOH	DOHA	QATAR	208	3
113	ZAG	ZAGREB	CROATIA	161	12
114	KER	KERMAN	IRAN	151	4
115	MDY	MIDWAY ISLAND	MIDWAY IS	86	2
116	PPG	PAGO PAGO	AMERICAN	75	6
117	IFR	ISTRES	FRANCE	67	8
118	ASM	ASMARA	ERITREA	45	1
119	ANC	ANCHORAGE	UNITED ST	26	1
120	SDQ	SANTO DOMINGO	DOMINICAN	23	2
121	TRS	TRIESTE	ITALY	17	3
122	KPO	POHANG	KOREA SOU	16	1
123	QUI	CHUQUICAMATA	CHILE	7	2
124	BTI	BARTER ISLAND	UNITED ST	6	1
125	HRG	HURGHADA	EGYPT	5	1
126	PMI	PALMA DE MALLORCA	SPAIN	3	2
127	SBE	MUSCAT	OMAN	1	1
		TOTAL		**WEIGHT (lbs.)**	**SHIPMENTS**
		top 22		**39,421,370**	**160,579**
			tons	19,711	
		system		**44,409,271**	**183,215**
			tons	22,205	
		PERCENT		**88.77**	**87.65**

Appendix C: Origin-APOD Demand Matrix.
(Weight in Pounds from 1 April - 30 June 1996)

Origin	1 ASP	2 BAH	3 DHA	4 DNA	5 EDF	6 HIK	7 HOW	8 KEF	9 KWA	10 KWI	11 MHZ	12 NBW	13 NRR	14 OKO	15 OSN	16 PLA	17 RMS	18 RTA	19 RUH	20 SIZ	21 THU	22 UAM	TOTAL
											Aerial Port of Debarkation												
1 Anniston AL		6	1,090	50	776	2,924	111	100		8,505	16	158,816	367	97	11,003		120,742	2	345	5	60	7	305,022
2 Washington DC	15,342	67,958	9,746	44,014	2,515	34,573	21,964	24,074		109	6,394	9,205	4,536	33,118	131,229	2,076	146,510	11,625	9,629	8,087		9,637	592,341
3 Camp Lejuene NC				29,780			4,273	6,762			405	27,951	23,158	4,630	66		1,396	32,996		40,728		1,019	173,164
4 Charleston SC		4,054	867	4,070	856	50,049	33,346	13,596	1,060		11,536	1,044	36,521	4,886	4,237	65	30,493	3,551	50	12,775		478	213,534
5 Chicago IL			5,084	927	110						5,465			502	7		135,625	54	2,847				150,621
6 Columbus OH		4,102	7,357	2,589	996	7,685	3,527	825	78	357	3,735	120	3,314	9,901	4,489	18	25,627	7,730	7,024	9,835	1,934	8,194	109,437
7 Corpus Christi TX		3,874	164	2,194	381	8,630	10,015	433			261	15	590	8,289	27,532	505	34,678	39		701		94	98,395
8 Crane IN		565		5,944			69,806	7,018				124,840	26,471	25			2,890	8,680		2,669		7,465	256,373
9 Dover AFB DE		6,697	286	5,342	135	626	1,981	3,079			247,183	3,510	4,072	2,874	2,218	578	1,843,176	29,930	624	2,976		9	2,155,296
10 Eglin AFB FL		1,370	32,691	45,590	4,222	20,033	30,402	8,756			3,758	22,885	5,533	21,842	58,836	1,058	36,977	9,710	793	8,482	370	1,224	314,532
11 Fort Worth TX		690	19,232	1,231		5,967	13,923		25	10,695	706		9,887	457	264,407	13,422	10,636	294	2,569	698	189,234	146	544,219
12 Ft Benning GA			481	345		11,757	6,969				871		9,756	1,212	43,295	540	48,738			1,030			124,994
13 Ft Bragg NC			7,129	10,679	5,037	7,020	19,492						2,332	9,751	140,113	3,601	20,919	747	7,313	1,076		923	236,132
14 Ft Campbell KY		3,273			1,170	6,359	7,486	7,995			247	670	340	1,705	71,818	685	19,409	245	5,530	1,310		382	128,624
15 Ft Hood TX			3,846	1,252		787	8,140				2,437		4,853	3,352	79,210	2,217	30,382		2,359	521			139,356
16 Ft Huachuca AZ			2,918	346	1,177		3,474	784			56			1,172	70,494		28,050	250		2,922		168	111,811
17 Ft Knox KY				2,705	522	5,576						305	8,248		51,158		3,975	330	828	1,523		1,363	76,533
18 Ft Rucker AL						12,036	2,975				665		9,156	900	109,085	3,027	40,980		200				179,024
19 Ft Stewart GA		814	345	631	684	9,834	2,670			551	338		2,341	268	91,730	614	62,791	450				192	174,253
20 Hill AFB UT		5,501	70,063	17,672	10,037	17,140	6,055	711	780	1,464	35,970	211	1,422	34,994	386,168	1	85,876	2,149	14,339	15,504	903	17,539	724,499
21 Huntsville AL		274	118		7,392	393	2,087		840	158	2,217			715	71,520	358	5,946						92,018
22 Jacksonville FL		24,498		2,640	614	11,748	1,560	7,618			162	6,782	5,131	5,905			9,511	7,264		23,700		1,410	108,543
23 Kessler AFB MS		41,556	3	4,979		6,607	1,629	1,639			2,172	389	4,317	2,858	9,698	1	5,723	1,672	964	2,402	3,473	915	90,997
24 Lathrop CA		26,442	46,333	209,568	80,919	577,884	10,825	2,752	20,036	3,186	17,673	3,774	5,490	460,033	249,834	592	96,101	6,858	2,785	29,307	24,097	197,304	2,071,793
25 Lemoore NAS CA		98		421		5,290	85	1			4		11	68,485				479		669		1,216	76,759
26 Malmstrom MT				658	760	972	545	850			320	200		2,738	11,695		476	840	240		40,210	1,448	61,952
27 McChord AFB WA		213	360	30,742	30,889	75,244	2,719	313			2,516	244	340	20,826	38,204	1,960	19,470	830	9,357	2,726	4	4,344	241,301
28 McClellan AFB CA	348,451	650	22,049	7,387	8,882	53,841	12,363	507	34	381	42,796	55	378	33,901	29,081	2,500	63,876	1,223	7,391	1,865	3,971	3,940	645,522
29 McGuire AFB NJ		100,877	131,021	56		114	11,750	110,049		2,465	31,382	312	8,043	7,841	1,243	18	501,666	20,643	32,981	20,327	20,109	3,100	1,003,997
30 Memphis TN		4,941	42,433	3,018	1,031	29,997	14,183	874	199	3,670	9,090	127	4,191	11,063	15,288	4	106,233	3,146	12,306	16,091	428	3,583	281,896
31 Monterrey CA		22,633		1,490	1,145		9,618	447	1,420		635		2,534	5,088	2,109		1,764	177		150		360	49,570
32 Nellis AFB NV		225	1,657	2,907	1,020	215	1,259	243			5,703			1,268	19,097	2,554	48,176		342	3,198	841		88,705
33 New Cumberland PA	1	34,557	316,869	69,580	21,613	138,145	570,393	10,917	2,909	1,523,192	141,940	31,906	186,540	143,772	50,961	278,204	8,410,153	39,758	35,676	113,235	18,815	48,321	12,187,457
34 New York NY		996	1,650							5,908					6,300		151,440		12,485				178,779
35 Norfolk VA	269	285,559	109,335	24,174	2,052	70,608	89,525	700,134	233	73,571	28,259	232,211	132,952	144,352	59,301	23,690	174,119	106,993	108,377	357,257	66,430	28,730	2,818,131
36 Oak Harbor WA		3,415		2,269		8,291		902					9,516	20,954	3			2,059		3,214		3,250	53,873
37 Oakland CA		10,607		12,234	3,964	55,943	599	974	332,470			2,664	372	66,847	3,585		6,328	5,605		3,999		8,667	514,858
38 Offutt AFB NE			36	5,514	650	4,931		256			843	125		5,483	14,213		30,513		17,529				80,093
39 Orlando FL				900						924	46,941			10,704			689,705	8,709		9,114			766,997
40 Palmetto GA		1,964	40,790	1,872	530	5,472	1,283	142		2,704	3,847	793	1,286	1,511	8,583	59	119,844	1,090	1,134	1,157	458	996	195,515
41 Peterson AFB CO				3,229			960		195		306			193	614		1,024				92,250	30	98,801
42 Philadelphia PA		17	167	11,588	4	7,369	49,409	164		27	15,371	4	54	26,761	22,121		42,513	3,845	82	1,935		1,997	183,428
43 Richmond VA		21,500	108,016	18,680	9,183	74,010	33,633	3,659	1,665	13,096	37,178	1,107	30,078	79,686	73,962	915	310,800	10,332	30,323	53,096	4,984	16,006	931,909
44 Robins AFB GA			30,236								27,935			1,475	39,788		77,484						176,918
45 Rock Island IL		5	1	430	330		54				51,093			1	2,033		201,798	650	2	1			256,398
46 San Antonio TX		7,014	148,860	66,668	55,307	17,391	2,889	613		1,400	18,865	5	2,651	20,825	8,532	3	211,965	1,140	1,514	1,937	664	5,853	574,096
47 San Diego CA	13	43,624	1,695	45,431	1,756	205,901	6,690	9,451			4,879	402	8,171	223,102	6,618	10	12,110	24,919	147	60,854	10	28,911	684,694
48 Scott AFB IL		10,530	1,390	2,791	1,010	8,440	2,014	495			3,944			6,076	13,739		17,898	386	22	2,458	1,312	911	73,416
49 Shaw AFB SC		930	66,090	1,435	1,288	422	1,784	1,888		315	149			3,430	3,818	8	33,298		2,842	726	1,530	405	120,358
50 Texarkana		1,158	15,036	2,363	7	7,284	1,208	88		4,700	7,908	1	2,086	1,912	111,633	535	119,679	804		2,127	1,464	1,020	281,013
51 Tinker AFB OK		61	33,681	13,649	11,605	4,621	39,659	217	88	10	18,788	1	2	8,722	91,894	117	58,396	2,739	30,979	345	1,128	1,868	318,570
52 Tobyhanna PA		483	4,924	1,559	2,940	8,326	10,086	382	7,452	102,070	4,560	8	21,035	11,861	212,595	21	70,013	582	117	367	20	1,762	461,163
53 Travis AFB CA			2	49,761	102,913	115,594	59	1,003	107	91,290	8,125	60	563	191,371	95,544		21,638	908		2,683		78,789	760,410
	ASP	BAH	DHA	DNA	EDF	HIK	HOW	KEF	KWA	KWI	MHZ	NBW	NRR	OKO	OSN	PLA	RMS	RTA	RUH	SIZ	THU	UAM	33,338,090
TOTAL	364,076	743,731	1,284,051	773,354	376,422	1,696,049	1,125,477	930,711	369,591	1,850,748	855,644	630,742	578,638	1,729,734	2,820,701	339,956	14,349,530	362,433	362,045	825,782	474,699	493,976	33,338,090

Appendix D: Macro to Produce CPLEX Readable Linear Program

```
'   The following set of subroutines creates a CPLEX readable file
'   containing the transshipment problem examined in the 1997
'   thesis of Capt L Dingle.
'
'
'   Macro programmed by:  Maj R Hill, AFIT/ENS
'
'
'   Cautionary notes:
'
'       This macro is not intended to be a general purpose formulation
'   tool.  As such there are certain aspects of the code that look for
'   specific data in specific locations in the Main worksheet.
'   Furthermore, input error checking is kept to a minimum.
'
'
'               Declare global / public variables
'
'

    Public OriginNames(1 To 60) As String
    Public APOENames(1 To 15) As String
    Public APODNames(1 To 25) As String
    Public Supply(1 To 60) As Double
    Public Demand(1 To 25) As Double
    Public APOECapacity(1 To 15) As Double
    Public APOEFixedCosts(1 To 25) As Double
    Public APOEThruPutCosts(1 To 25) As Double
'
'

    Sub OutputCPLEX()

    Sheets("Main").Select
'
'
'   Open desired output file in which to place the data
'
'

    sPath = Cells(8, 15)
    sFile = Cells(10, 15)
    xTarget = sPath & "\" & sFile & ".dat"
    yTarget = sPath & "\" & sFile & ".idx"
    Open xTarget For Output As #10
    wIndex = Cells(12, 15)
    If wIndex = "yes" Then
        IndexFlag = True
    End If
'
'
'   Next read the Origin, APOE, and APOD data into the public
'   storage arrays.  Keeping the data in memory speeds up the
'   processing as opposed to accessing the cells directly from the
'   spreadsheet.
'
'

    NumOfOrigins = Cells(3, 1)
    NumOfAPOEs = Cells(16, 11)
    NumOfAPODs = Cells(3, 6)
'
'   Read in the origin data, names and supply information
'   This data starts in row four of the sheet "Main"
```

```
'
    For i = 1 To NumOfOrigins
        Supply(i) = Cells(i + 3, 3)
        OriginNames(i) = Cells(i + 3, 2)
    Next i
    TotalSupply = Cells(3, 3)
'
'   Read in the APOD data, names and demand information
'
    For i = 1 To NumOfAPODs
        Demand(i) = Cells(i + 3, 9)
        APODNames(i) = Cells(i + 3, 8)
    Next i
    TotalDemand = Cells(3, 9)
'
'
'       The BigM value is used to spoof the throughput constraints on
'   each of the APOEs.  Currently there is no constraint on throughput.
'   However, we wish to have that capability built into the formulation.
'
    BigM = Application.Max(TotalSupply, TotalDemand)
'
'   Read in the APOE data, names, Capacities, Operating Costs
'
    For i = 1 To NumOfAPOEs
        APOENames(i) = Cells(i + 16, 11) & " -- " & Cells(i + 16, 13)
        APOEFixedCosts(i) = Cells(i + 16, 15)
        APOEThruPutCosts(i) = Cells(i + 16, 16)
            If Cells(i + 16, 14) = 0 Then
                APOECapacity(i) = BigM
            Else
                APOECapacity(i) = Cells(i + 16, 14)
            End If
    Next i
'
'       Next read in the shipping cost data
'
    CostFromOrigin = Cells(2, 15)
    CostFromAPOE = Cells(4, 15)


'
'
'
'       The following code generates an index of the Origin, APOE, and
'   APOD names according to the name used within the CPLEX formulation.
'   The index file name matches the formulation name with the exception
'   of using the .idx suffix versus the .dat suffix.
'
    If IndexFlag Then
        Open yTarget For Output As #9
        Print #9, "Variables in this model are of the following form:"
        Print #9, "     O#A#  --  Flow from Origin node # to APOE node
#"
        Print #9, "     A#D#  --  Flow from APOE node # to APOD node #"
        Print #9, "where the node numbers are defined in the following
manner:"
        Print #9, "First is the list of Origin nodes in the model:"
        For i = 1 To NumOfOrigins
            Print #9, "Origin node ", i, " coded as ", "O" &
LTrim(Str(i)), " is ", OriginNames(i)
        Next i
            Print #9, "Next is the list of APOE nodes in the model:"
        For i = 1 To NumOfAPOEs
```

```
                Print #9, "APOE node ", i, " coded as ", "A" &
LTrim(Str(i)), " is ", APOENames(i)
            Next i
                Print #9, "Finally is the list of APOD nodes in the model:"
            For i = 1 To NumOfAPODs
                Print #9, "APOD node ", i, " coded as ", "D" &
LTrim(Str(i)), " is ", APODNames(i)
            Next i
                Print #9, "Variable Z(J) is 0 if APOE J closed, 1 if APOE J
is open"
                Print #9, "Variable YA#D# is 1 if this APOE uniquely serves
D#"
                Print #9, "  "
                Print #9, "Each of the constraints in the formulation is
labeled."
                Print #9, "The following is the coding used for the labels:"
                Print #9, "  Obj:    ---  Objective function of the problem"
                Print #9, "   S#:    ---  Supply constraints"
                Print #9, "   D#:    ---  Demand constraints"
                Print #9, "  FC#:    ---  Net flow, or flow capacity
constraint"
                Print #9, "  UJ#:    ---  Unique APOE to APOD junction
constraint"
                Print #9, "  PC#:    ---  Aerial port capacity constraint"
                Print #9, "  LC#:    ---  Link capacity to APOD constraints"
                Print #9, "  SC#:    ---  Special demand constraints"
                Print #9, "End of List...."

            Close #9
        End If
'
'
'       The following section of the macro formats and outputs the
objective
'   function for the problem.
'
'       There are three pieces of the objective function.  The first
piece
'   represents the cost of shipping material from the Origin to the
APOE.
'   The second piece represents the cost of shipping material from the
APOE
'   to the APOD.  The final piece represents the fixed operating costs
for
'   opening up an APOE.
'
'
Print #10, "Minimize"
'
'
    TermsPerLine = 5
    Sheets("OriginDistances").Select
    xRow = 4 + NumOfOrigins
    yCol = 2 + NumOfAPOEs
'
'       Create the first piece of the objective function...the Origin to
APOE
'   shipment costs.  The code includes test for zero objective function
values,
'   which are skipped over.
'
    Set xRange = ActiveSheet.Range(Cells(5, 3), Cells(xRow, yCol))
    WorkTerm = "Obj: "
```

```
    NumInIt = 0
    For Each C In xRange
        xRow = C.Row
        yCol = C.Column
        zCost = CostFromOrigin * C.Value + APOEThruPutCosts(Cells(3,
yCol))
        If zCost <> 0 Then
            WorkTerm = WorkTerm & LTrim(Str(zCost)) & " "
            WorkTerm = WorkTerm & "O" & LTrim(Str(Cells(xRow, 1)))
            WorkTerm = WorkTerm & "A" & LTrim(Str(Cells(3, yCol))) & " +
"
            NumInIt = NumInIt + 1
        End If
        If NumInIt >= TermsPerLine Then
            Print #10, WorkTerm
            WorkTerm = ""
            NumInIt = 0
        End If
    Next C
'
'
'       Create the second piece of the objective function...the APOE to
APOD
'   shipment costs.
'       Notice I do not want to reset the WorkTerm or NumInIt since I am
still
'   building the same objective function value.
'       The code includes test for zero objective function values,
'   which are skipped over.
'
'
    Sheets("APODDistances").Select
    xRow = 4 + NumOfAPODs
    yCol = 2 + NumOfAPOEs
    Set xRange = ActiveSheet.Range(Cells(5, 3), Cells(xRow, yCol))
    For Each C In xRange
        xRow = C.Row
        yCol = C.Column
        zCost = CostFromAPOE * C.Value
        If zCost <> 0 Then
            WorkTerm = WorkTerm & LTrim(Str(zCost)) & " "
            WorkTerm = WorkTerm & "A" & LTrim(Str(Cells(2, yCol)))
            WorkTerm = WorkTerm & "D" & LTrim(Str(Cells(xRow, 1))) & " +
"
            NumInIt = NumInIt + 1
        End If
        If NumInIt >= TermsPerLine Then
            Print #10, WorkTerm
            WorkTerm = ""
            NumInIt = 0
        End If
    Next C
'
'
'       Create the last piece of the objective function...the APOE fixed
'   operating costs given that the APOE has been opened.  The decision
to open
'   the APOE is captured in the Z# variable within the formulation.
'
'       Notice I still do not want to reset the WorkTerm or NumInIt
since I
'   building the same objective function value.
'
```

```
'
    For j = 1 To NumOfAPOEs - 1
        WorkTerm = WorkTerm & LTrim(Str(APOEFixedCosts(j))) & " Z" &
LTrim(Str(j)) & " + "
        NumInIt = NumInIt + 1
        If NumInIt >= TermsPerLine Then
            Print #10, WorkTerm
            WorkTerm = ""
            NumInIt = 0
        End If
    Next j
    WorkTerm = WorkTerm & LTrim(Str(APOEFixedCosts(NumOfAPOEs)))
    WorkTerm = WorkTerm & " Z" & LTrim(Str(j))
    Print #10, WorkTerm
'
'       Now ready to start formating and printing out the constraints
'
'       All but the Special Demand constraints are generated based on
the data
'   stored in the public arrays previously filled from the "MAIN"
worksheet.
'
    TermsPerLine = 8
    Print #10, "Subject to"
'
'       The next section of code will generate the Supply constraints
'   Currently the code assumes that each origin will have non-zero
supply.
'   Thus there is no checking for zero values.
'
'Print #10, "Following are the Supply constraints:"
ConstraintNumber = 1
For i = 1 To NumOfOrigins
    WorkTerm = "S" & LTrim(Str(ConstraintNumber)) & ": "
    ConstraintNumber = ConstraintNumber + 1
    For j = 1 To NumOfAPOEs - 1
        WorkTerm = WorkTerm & "O" & LTrim(Str(i)) & "A" & LTrim(Str(j))
& " + "
    Next j
    WorkTerm = WorkTerm & "O" & LTrim(Str(i)) & "A" &
LTrim(Str(NumOfAPOEs)) & " <= "
    WorkTerm = WorkTerm & Str(Supply(i))
    Print #10, WorkTerm
Next i
'
'
'       The next section of code will generate the Demand constraints
'   As with the supply constraints, the current code that follows
assumes
'   that each APOD will have a non-zero demand.
'
'Print #10, "Following are the Demand constraints:"
ConstraintNumber = 1
For i = 1 To NumOfAPODs
    WorkTerm = "D" & LTrim(Str(ConstraintNumber)) & ": "
    ConstraintNumber = ConstraintNumber + 1
    For j = 1 To NumOfAPOEs - 1
        WorkTerm = WorkTerm & "A" & LTrim(Str(j)) & "D" & LTrim(Str(i))
& " + "
    Next j
    WorkTerm = WorkTerm & "A" & LTrim(Str(NumOfAPOEs)) & "D" &
LTrim(Str(i)) & " = "
    WorkTerm = WorkTerm & Str(Demand(i))
```

```
    Print #10, WorkTerm
Next i
'
'
'       The next section of code will generate the Flow Conservation
constraints.
'   Essentially a flow conservation constraint ensures that all goods
that flow
'   into an APOE in fact flow out...In-flow = Out-flow.
'
'Print #10, "Following are the Flow Conservation constraints:"
ConstraintNumber = 1
For j = 1 To NumOfAPOEs
    TermsInIt = 0
    WorkTerm = "FC" & LTrim(Str(ConstraintNumber)) & ": "
    ConstraintNumber = ConstraintNumber + 1
    For i = 1 To NumOfOrigins - 1
        WorkTerm = WorkTerm & "O" & LTrim(Str(i))
        WorkTerm = WorkTerm & "A" & LTrim(Str(j)) & " + "
        TermsInIt = TermsInIt + 1
        If TermsInIt >= TermsPerLine Then
            Print #10, WorkTerm
            WorkTerm = ""
            TermsInIt = 0
        End If
    Next i
    WorkTerm = WorkTerm & "O" & LTrim(Str(NumOfOrigins))
    WorkTerm = WorkTerm & "A" & LTrim(Str(j)) & " - "
    TermsInIt = TermsInIt + 1
    For k = 1 To NumOfAPODs - 1
        If TermsInIt >= TermsPerLine Then
            Print #10, WorkTerm
            WorkTerm = ""
            TermsInIt = 0
        End If
        WorkTerm = WorkTerm & "A" & LTrim(Str(j))
        WorkTerm = WorkTerm & "D" & LTrim(Str(k)) & " - "
        TermsInIt = TermsInIt + 1
    Next k
    WorkTerm = WorkTerm & "A" & LTrim(Str(j))
    WorkTerm = WorkTerm & "D" & LTrim(Str(NumOfAPODs)) & " = 0.0"
    Print #10, WorkTerm
Next j
'
'
'       The next section of code will generate the constraints ensuring
'   that each APOE uniquely serves an APOD.
'
'
'Print #10, "Following are the APOE-APOD uniqueness constraints:"
ConstraintNumber = 1
For k = 1 To NumOfAPODs
    WorkTerm = "UJ" & LTrim(Str(ConstraintNumber)) & ": "
    ConstraintNumber = ConstraintNumber + 1
    For j = 1 To NumOfAPOEs - 1
        WorkTerm = WorkTerm & "YA" & LTrim(Str(j)) & "D" & LTrim(Str(k))
& " + "
    Next j
    WorkTerm = WorkTerm & "YA" & LTrim(Str(NumOfAPOEs)) & "D" &
LTrim(Str(k)) & " = 1"

    Print #10, WorkTerm
Next k
```

```
'
'
'       The next section of code will generate the Aerial port capacity
'   constraints.  Currently, there is no requirement to enter capacities
'   on any of the APOEs.  When no capacity is specified, this macro uses
'   the BigM value (method) for ensuring sufficient capacity for each
APOE.
'       BigM is taken here as the maximum of Total Supply or Total
Demand.
'
'
'Print #10, "Following are the Aerial Port capacity constraints:"
ConstraintNumber = 1
For j = 1 To NumOfAPOEs
    WorkTerm = "PC" & LTrim(Str(ConstraintNumber)) & ": "
    ConstraintNumber = ConstraintNumber + 1
    TermsInIt = 0
    For i = 1 To NumOfOrigins - 1
        WorkTerm = WorkTerm & "O" & LTrim(Str(i)) & "A" & LTrim(Str(j))
& " + "
        TermsInIt = TermsInIt + 1
        If TermsInIt >= TermsPerLine Then
            Print #10, WorkTerm
            WorkTerm = ""
            TermsInIt = 0
        End If
    Next i
    WorkTerm = WorkTerm & "O" & LTrim(Str(NumOfOrigins)) & "A" &
LTrim(Str(j))
    WorkTerm = WorkTerm & " - " & LTrim(Str(APOECapacity(j))) & " Z" &
LTrim(Str(j))
    WorkTerm = WorkTerm & " <= 0.0 "
    Print #10, WorkTerm
Next j
'
'
'       The following section generates APOE to APOD link capacity
constraints.
'   These constraints kick in when a given APOE to APOD link is
initialized to
'   uniquely serve each of the APOD.
'       There is one constraint for each of the APOE - APOD
combinations.
'
'       Here again, there is no specification of link capacities within
the
'   provided data.  For this coding, the logic is to ensure that no link
'   ships more than the capacity of the APOE from which it originates.
Thus
'   the BigM value is again used in lieu of true capacity constraint
value.
'
'
'Print #10, "Following are the Link capacity, APOE to APOD constraints:"
ConstraintNumber = 1
For j = 1 To NumOfAPOEs
    For k = 1 To NumOfAPODs
        WorkTerm = "LC" & LTrim(Str(ConstraintNumber)) & ": "
        ConstraintNumber = ConstraintNumber + 1
        WorkTerm = WorkTerm & "A" & LTrim(Str(j)) & "D" & LTrim(Str(k))
        WorkTerm = WorkTerm & " - " & LTrim(Str(APOECapacity(j))) & " "
        WorkTerm = WorkTerm & "YA" & LTrim(Str(j)) & "D" & LTrim(Str(k))
        WorkTerm = WorkTerm & " <= 0.0"
```

```
            Print #10, WorkTerm
        Next k
    Next j
'
'
'       The following section generates the special consideration supply
to
'   demand constraints based on the data within the Special Demand
matrix
'   contained in the SpecialDemand sheet.
'
'
'       Define the special demand matrix as an object and then examine
'   each cell in the defined range.
'
'    Print #10, "Following are the Special Demand constraints:"
    Sheets("SpecialDemand").Select
    xRow = 6 + NumOfOrigins
    yCol = 3 + NumOfAPODs
    Set xRange = ActiveSheet.Range(Cells(7, 4), Cells(xRow, yCol))
'
'       Next consider each cell in the defined range
'
    ConstraintNumber = 1
    For Each C In xRange
        If C.Value > 0 Then
            xRow = C.Row
            yCol = C.Column
            For j = 1 To NumOfAPOEs
                WorkTerm = "SC" & LTrim(Str(ConstraintNumber)) & ": "
                ConstraintNumber = ConstraintNumber + 1
                WorkTerm = WorkTerm & "O" & LTrim(Str(Cells(xRow, 1)))
                WorkTerm = WorkTerm & "A" & LTrim(Str(j)) & " - "
                WorkTerm = WorkTerm & LTrim(Str(C.Value))
                WorkTerm = WorkTerm & " YA" & LTrim(Str(j))
                WorkTerm = WorkTerm & "D" & LTrim(Str(Cells(4, yCol)))
                WorkTerm = WorkTerm & " >= 0.0"
                Print #10, WorkTerm
            Next j
        End If
    Next C
'
'
'       All the standard constraints are now placed into the file.
'
'       The following section adds the non-negativity constraints and
'   the binary constraints to the problem.
'
'       The default bounds are 0 <= x <= infinity.  These default bounds
'   apply to each of the O#A# and A#D# variables in the problem.
'
'       In this initial formulation, the YA#D# variables are allowed to
be
'   real variables bounded above by 1.  In actuality, these will likely
have
'   to be recoded as Integer variables.
'
'
    Print #10, "Bounds"
    For j = 1 To NumOfAPOEs
        For k = 1 To NumOfAPODs
            WorkTerm = "YA" & LTrim(Str(j)) & "D" & LTrim(Str(k))
            WorkTerm = WorkTerm & " <= 1"
```

```
            Print #10, WorkTerm
        Next k
    Next j
'
'
'       Integer section follows.  By default, integer variables are
assumed
'   binary and provided the bounds of  0<= y <= 1.  This assumption is
used.
'
    Print #10, "Integers"
    WorkTerm = ""
    For j = 1 To NumOfAPOEs
        WorkTerm = WorkTerm & "Z" & LTrim(Str(j)) & " "
    Next j
    Print #10, WorkTerm
'
'
'       Finally END the file
'
Print #10, "End"
'
'   Close the file and return to the "MAIN" worksheet
'
    Close #10
    Sheets("Main").Select

    Beep
    Beep

    End Sub



    Sub Oops()

    Close

    End Sub

    Sub auto_open()
    Sheets("Module1").Visible = False
    End Sub

    Sub Reshow()
    Sheets("Module1").Visible = True
    End Sub
```

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13. ABSTRACT ***(Maximum 200 Words)***

This study performed an investigation on determining the appropriate number and locations of continental United States aerial ports. To accomplish this a linear programming formulation was adapted with the optimizing function based on trading off the cost of shipping cargo against port operating costs. Cargo would travel from CONUS origin, through aerial port of embarkation (APOE), to aerial port of debarkation (APOD) at minimum cost to the DOD. The need for the study was precipitated by continued reductions in the military budget, consolidation of defense depots, and the reduction in the number of personnel stationed overseas.

Cargo movement data was extracted from the Transportation Reporting and Inquiry System database for fiscal year 1996. This information was then used as deterministic demand at the APODs from particular origination cities. The demand had to be exactly met in the formulation. Applying the linear program resulted in the recommendation to operate only three aerial ports. They are Travis AFB, CA, Dover AFB, DE, and McGuire AFB, NJ saving over 11 million dollars a year.

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