NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

MODELING CLOSURE OF ARMY MATERIEL COMMAND INSTALLATIONS: A BI-CRITERIA MIXED INTEGER PROGRAMMING APPROACH

by

William J. Tarantino

September 1992

Thesis Advisor: Robert F. Dell

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b. OFFICE SYMBOL OR	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Including Security Classification)
MODELING CLOSURE OF ARMY MATERIEL COMMAND INSTALLATIONS: A BI-CRITERIA MIXED INTEGER PROGRAMMING APPROACH

12 PERSONAL AUTHOR(S)
TARANTINO, William J.

13 TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. Page Count
Master's thesis	FROM TO	1992, SEPTEMBER	84

16. SUPPLEMENTAL NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Base Closing, Integer Program, BRAC, AMC, Army Material Command

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The Army is reducing and reshaping its force structure to adapt to the nation's changing defense needs and budget constraints. In response to these changes, Army Materiel Command (AMC) will submit facility realignment and closure recommendations in FY93 and FY95. This thesis develops a bi-criteria mixed interger programming model with the objectives of minimizing operating costs and maximizing a measure of military value to assist AMC in the generation of alternative realignments. Realignment of depot maintenance, research and development, test and evaluation, and administative functions are considered on 32 AMC installations. An extensive empirical study demonstates the applicability of the developed approach.

20 DISTRIBUTION/AVAILABLTIY OF ABSTRACT [X] UNCLASSIFIED/UNLIMITED [ ] SAME AS RPT. [ ] DTIC	1a. REPORT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Robert F. Dell	22b. TELEPHONE (Include Area Code) (408)646-2853 22c. OFFICE SYMBOL OR/De

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE
S/N 0102-LF-014-6603 Unclassified

Approved for public release; distribution is unlimited

Modeling Closure of Army Materiel Command Installations: A Bi-Criteria Mixed Integer Programming Approach

by

William J. Tarantino
Captain, United States Army
B.S., United States Military Academy, West Point, 1981

Submitted in partial fulfillment
of the requirements for the degree

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1992

Author: William J. Tarantino

Approved by: Robert F. Dell, Thesis Advisor

Samuel H. Parry, Second Reader

Richard E. Rosenthal for

Peter Purdue Chairman
Department of Operations Research

ABSTRACT

The Army is reducing and reshaping its force structure to adapt to the nation's changing defense needs and budget constraints. In response to these changes, Army Materiel Command (AMC) will submit facility realignment and closure recommendations in FY93 and FY95. This thesis develops a bi-criteria mixed integer programming model with the objectives of minimizing operating costs and maximizing a measure of military value to assist AMC in the generation of alternative realignments. Realignment of depot maintenance, research and development, test and evaluation, and administrative functions are considered on 32 AMC installations. An extensive empirical study demonstrates the applicability of the developed approach.

DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

TABLE OF CONTENTS

I. INTRODUCTION

The United States Army is reducing and reshaping its force structure to adapt to the nation's changing defense needs and budget constraints. These changes will cause the Army's major commands to undergo significant restructuring. A special analyst group at the Army Materiel Command (AMC) is developing options to maintain acceptable mission performance at anticipated decreased operating budgets. This thesis develops an optimization model to assist AMC with Base Realignment and Closure (BRAC) recommendations.

A. ARMY MATERIEL COMMAND

AMC operates and maintains 50 major and 40 subordinate commodity, depot, and production installations, with a work force of over 100,000 civilian and military workers. This major Army command has an annual operating budget over $6.5 billion [Ref. 1] supporting diverse and far-reaching missions.

AMC missions include [Ref. 2]:

- equip and sustain a trained, ready army,
- provide equipment and services to other nations through the security assistance program,
- develop and acquire non-major systems and equipment,
- provide development and acquisition support to program managers,

- define, develop and acquire superior technologies,
- maintain the mobilization capabilities necessary to support the army in emergencies,
- continue to improve productivity and quality of life.

Each mission statement is defined by five to ten function statements. The essence of AMC is included in the major functions: maintenance, supply, production, research and development, test and evaluation, and administrative. Each function has unique support requirements which make realignment considerations different between functions. This thesis restricts the functions considered to research and development, depot maintenance, production, and administrative. This selection captures a significant part (approximately $2.0 billion) of AMC's $6.5 billion annual operating budget.

B. BASE REALIGNMENT AND CLOSURE

There have been four rounds of BRAC recommendations from 1988 to 1991 which the Army refers to as BRAC I, II, III, and BRAC 91. A brief summary of rounds I, II, and 91 are provided below. BRAC III only considered overseas installations and is not discussed (see [Ref. 3] for more information).

1. BRAC I

On 3 May 1988 the Secretary of Defense chartered a commission to recommend closure and realignment of military installations. The commission's recommendations for Army installations became known as BRAC I [Ref. 4] and were the first attempt at serious realignment for over a decade.

The commission took a two phase approach to analyze potential realignments. Phase I separated military installations into categories with similar missions. Installations within categories were compared on 21 mission related physical attributes grouped into five overall factors. Installations were evaluated for each attribute as either marginal for mission accomplishment, acceptable, or fully satisfactory. Potential closures were identified from this evaluation.

Phase II developed relocation alternatives for potential closures based on the physical attributes collected in Phase I and analyzed the potential cost savings. The commission developed recommendations for realignment but they were not fully implemented.

2. BRAC II

Due to a changing political climate and restructuring of the Army, BRAC II recommended realignment of Continental United States Bases (CONUS). BRAC II was stopped by Public Law 101-510 [Ref. 5] which established the Defense Base Closure and Realignment Act of 1990. This Act served as the official procedure for closure of most DoD installations and led to BRAC 91.

3. BRAC 91

Public Law 101-510 allows the Department of Defense to compile submissions in 1991, 1993, and 1995 for recommended closure and realignment [Ref. 5]. The following is an overview of the Army's methodology for determining BRAC 91 recommendations.

Governing the BRAC process was the desire to close or consolidate installations only when both economic and military factors were favorable. The military aspect included the desire to maximize force readiness, ensure the capability to expand to future requirements, provide adequate training facilities, and maximize the quality of life for their personnel. Economic concerns centered on potential long term savings, immediate cost, and impact on local communities.

The Army developed a procedure consistent with Public Law 101-510 and similar to that used by the 1988 commission. The military value of installations was developed in accordance with DoD criteria during Phase I. To be able to compare similar assets, installations were divided into seven categories, and quantitative information was gathered to determine an installation's ability to perform missions. This quantitative information was divided into the following five "Measures of Merit" [Ref. 4]:

- Mission Suitability,
- Mission Essentiality,
- Operational Efficiencies,

- Expandability,
- Quality of life.

Each Measure of Merit was divided into subelements. The subelements were weighted and combined linearly to obtain a numeric measure of the installation's military value. The installations were then ranked in relation to other installations in the same category.

The installation rankings were the starting point for Phase II of the process. Closure and realignment recommendations were made in Phase II following a multi-step process. Candidate closures were chosen from installations that had both a low military value score and did not possess unique characteristics. Additional installations affected by the reducing force structure were also considered.

Alternatives for realignment were manually determined from a list of potential closures and checked for feasibility. Within the feasibility check, issues of operation, return on investment (see COBRA [Ref. 6]), community impact, and environmental factors were considered.

4. Army Materiel Command Base Realignment and Closure

Past realignment analysis by AMC for BRAC 91 included economic analysis using the Cost of Base Realignment Action (COBRA) cost estimating relationships [Ref. 6], engineering estimates, analysis of current and future workloads, and consideration of BRAC attributes. AMC conducted sensitivity analysis in several key areas and over 20 scenarios were evaluated [Ref. 7]. "Vision 2000" was AMC's concept for streamlining base operations and mission support costs and was the culmination of their analysis [Ref. 8].

AMC is required to submit a BRAC scenario to the Army in 1993 and 1995 on which of its installations will be realigned or closed over the following two years. The basic principles governing their realignment proposal include [Ref. 4]:

- consolidation into the best, most efficient installations,
- maximize the quality of life and minimize hardships for all AMC personnel,
- consider costs and savings of realignments.

C. RELATED LITERATURE

There are several detailed Army reports on the BRAC process and past BRAC recommendations. They include reports from the BRAC commission and analysis from the Army Auditing Agency.

The Department of the Army *Base Closure and Realignment, Detailed Analysis* [Ref. 4] and the Department of Defense *Base Closure and Realignment Report* [Ref. 9] provide a history of BRAC, an in-depth analysis of the decision making process, and recommended realignments and closures. The AAA report: *Lessons Learned For Future Basing Studies* [Ref. 10] and information memorandum reports offer an independent agency's perspective on aspects of the studies with specific recommendations for future AMC submissions. The United States Army Corps of

Engineers Reorganization Study [Ref. 11] identifies the Corps' realignment decision making process and their objectives.

There is an ongoing research effort at The Naval Postgraduate School (NPS) by Professors Dell, Parry, and Rosenthal [Ref. 12] to provide optimization models for base realignment and closure. The applicability of their modeling approach was demonstrated in Singleton [Ref. 13] a NPS master's thesis advised by Professors Dell and Parry. The model under development for maneuver and training installations is referred to as Optimal Stationing Units to Bases (OSUB). OSUB is a bi-criteria mixed integer programming model. The two objectives [Ref. 12] seek to maximize military value by:

- obtaining the best fit of units to bases,
- and minimize operating cost.

The operations research literature refers to problems with the characteristics of OSUB as facility location problems. There are abundant references in the operations research literature on this problem. Francis, McGinnis, and White [Ref. 14] discuss aspects of the location problem as well as provide a selected review of existing literature. Current, Min, and Schilling [Ref. 15] provide a review of the literature available for multiobjective location problems. Both reviews are extensive in the number of articles considered but neither offer a model for considering military value.

D. MODELING APPROACH

This thesis develops a bi-objective mathematical model similar to OSUB for AMC using information gathered from BRAC 91 about AMC's operating costs and personnel information.

The goals of the mathematical model include:

- obtain the best "military value",
- minimize AMC's operating costs while maintaining a minimal level of support,
- limit up-front, immediately incurred realignment costs (travel, hire, and construction),
- realign specific functions.

Using these goals, the model analyzes administration, maintenance, research and development, and test and evaluation functions at Depot, Commodity, and Production installations.

E. THESIS OUTLINE

Chapter II discusses the model, its assumptions, and its features. Chapter III reports computational results which are highlighted with graphical examples. Conclusions are discussed in Chapter IV. An extensive description of data is in Appendix A. Appendix B details model implementation with the aid of numerous examples. Appendix C lists support personnel ratios, base operation personnel ratios, and installations considered with corresponding functions. A description of realignment reports and an example computer listing generated by the model are included in Appendix D.

II. A MODEL FOR AMC REALIGNMENT

A. INTRODUCTION

AMC is required to submit realignment and closure recommendations in 1993 and 1995. This chapter contains a bi-criteria mixed integer programming model to assist AMC in determining and analyzing feasible realignment alternatives. The model considers realignment of 32 installations and four mission functions: depot maintenance, research and development (R&D), test and evaluation (T&E), and administrative. Installation supply and production functions are contained in the model but are not considered for realignment.

1. Model Objectives

There are two distinct and conflicting objective functions in the model: operating cost and "military value". The operating cost objective includes both fixed and variable costs. The fixed costs are constant regardless of personnel levels and include family housing maintenance, Real Property Maintenance (RPMA), and the civilian salary and utility consumption for supply and production functions that are not considered for realignment. Personnel levels at each installation determine the variable cost which consists of civilian salaries, utility consumption, military housing, and RPMA for any new construction. Data and sources for variable and fixed costs are explained in Appendix A.

The military value objective seeks to minimize lost personnel experience years. Both an Army Corps of Engineers realignment study [Ref. 11] and AMC [Ref. 1] identify personnel as one of their most important resources. The Army has established that approximately 30% [Ref. 1] of a civilian work force will not transfer to a new location if their job is moved. Any realignment therefore results in a loss of experienced personnel and decreases a work forces' average experience level. As such, lost personnel experience years serves as a measure of disruption to current operations and therefore a loss of military value.

The model's two other goals to realign designated facilities and observe approved limits on transportation, construction, and hiring costs are achieved with constraints.

2. Modeling Assumptions

There are a number of modeling issues which require assumptions to facilitate completion of the model. These issues are minor and do not decrease model resolution. The assumptions listed below are primarily related to data and can be easily modified.

- A strength of the model is the ability to change personnel levels and allow the model to optimize realignment. AMC anticipates a loss of aproximately 25% of their workforce by fiscal year 1995 [Ref. 8]. Due to unknown future personnel levels, the model is implemented using present levels. Personnel lost during realignment are replaced at their new installation and the cost associated with those personnel are included in AMC's operating costs.

- Administrative and maintenance functions can be divided and realigned to different installations. Their personnel levels are not exact therefore, fractions of a person may be moved. R&D and T&E functions are not considered divisible. For example, a realigned R&D function can only move to one location.

- The realignment that takes place may not result in a closure. Therefore, a decreased function level at an installation is an acceptable condition.

- There are fixed costs at all installations regardless of realignments because the model does not consider moving all AMC functions or tenant units.

Additional assumptions concerning aspects of data are included in Chapter III of this thesis.

B. UNIQUE MODELING CONSIDERATIONS

The following are unique features of the model:

- Functions are allowed to realign even if they place excessive resource requirements on available facilities. This introduces elastic variables [Ref. 16] which are restricted by realignment costs and construction limitations.

- AMC installations are grouped into depot, commodity, and production categories. A function can realign only to facilities within its category (eg. depot maintenance missions can only be realigned to a depot maintenance facility), except administrative functions which can move to any category. There are also non-transferable missions on facilities (supply, production) which add additional limitations to any realignment.

- A group of designated facilities have to be incorporated into other facilities regardless of available resources. This forces a minimum realignment.

C. MODEL

The model is presented in its general form below. A more extensive discussion of the objectives, constraints, and parameters is presented in Appendix B.

1. Indices

- f,f' installations considered for realignment,
- j functions (administrative, R&D, T&E, depot maintenance),
- e personnel types (civilian, accompanied and unaccompanied officer and enlisted),
- L a function forced to realign,
- NL a function not forced to realign,
- r resource available at an installation and required by functions (facility space, support personnel, base operations personnel, buildable acres, water utilities, electric utilities, military housing, civilian personnel),
- s a subset of the categories in r that contain the facility space available at an installation (administrative, R&D, T&E, depot maintenance),
- h a subset of the categories in r that contain the military housing available at an installation (officer and enlisted family, accompanied, and unaccompanied),
- c a subset of the categories in r that contain the construction at an installation (facility space, water utilities, and electric utilities),
- o one time costs (transportation, hire, and construction),
- t a subset of the categories in o that contains transportation and hire.

2. Data

- $CCOST_{fc}$ construction cost at installation f for category c,
- FC_f fixed costs associated with operating installation f,
- MAXOTC maximum one time cost,
- $MCOST_{tff'j}$ transportation cost to move function j from installation f to f' for subset t,
- $PERS_{fje}$ number of personnel e in function j at installation f,
- RES_{fr} resource r available at installation f,
- $RRES_{jer}$ required resource r for personnel type e at installation j,
- $RPMA_f$ Real Property MAintenance cost for installation f,
- VC_f variable costs per person at installation f,
- YL_{fj} years lost if function j at installation f is moved.

3. Variables

- $X_{ff'j}$ represents the percent of function j that moves from installation f to f' (X is continuous for administrative and maintenance missions, binary for T&E and R&D functions).

- DEV_{fr} is an elastic variable for a deviation of resource r at installation f.

- P_{fje} is a derived variable which simplifies equations and represents the new level of personnel type e for function j at installation f.

$$P_{fje} = \sum_{f'} PERS_{fje}(1-X_{ff'j}) + \sum_{f'} \; PERS_{f'je}X_{f'fj} \quad \forall\, f,j,e$$

4. Formulation

a. *Objectives*

MINIMIZE Operating Cost

$$\sum_f \Big(\sum_e \big(\sum_j VC_{fe}P_{fje} + \big(\sum_h VHA_{fe}DEV_{fh}\big)\big) \\ + \big(\sum_s RPMA_f DEV_{fs}\big) + FC_f\Big)$$

MINIMIZE Lost Experience Years

$$\sum_f \sum_{f' \in nl} \sum_j YL_{ff'}X_{ff'j}$$

The first objective minimizes AMC's operating cost. The first element, $VC_{fe}P_{fje}$, represents the variable costs at the new personnel level and is a combination of civilian salaries, utility, and housing costs. The variable factor $VHA_{fe}DEV_{fh}$ is the cost of housing any military off-post due to lack of military housing at the installation. The third variable cost $RPMA_fDEV_{fs}$ is for maintenance of any newly constructed buildings. FC_f is the fixed cost at installation f which is a combination of housing maintenance costs, RPMA costs for existing buildings, and the cost (civilian salary, utilities) for the AMC personnel that are not considered for realignment.

Any realignment or closure will have an impact on AMC's personnel and a disruption in performance. The second objective seeks to minimize this impact. Personnel who accept early retirements and personnel who choose not to move determine the lost experience years anticipated by realignment. Two methods are used to quantify the percentage of personnel who do not move. One method uses the Army standard factor of 28.7% [Ref. 17]. This thesis proposes a second method that uses a range of values which are dependent on pay grades. The method distributes the percent lost for different pay grades assuming personnel with higher pay grades, having lived longer in the current area, are less likely to move and personnel with the least experience, having the least time invested in AMC, are also less likely to move. The varied percentages are shown in Figure 1 under the loss column.

The lost experienced man years incurred during a realignment are calculated using the values for each pay grade, estimated years per grade, and estimated losses that are listed in Figure 1. For example, a realignment of 20 GS3 personnel results in 10 (20*.5) lost personnel and 30 (10*3) years of lost experience (A more extensive example is provided in Appendix B).

GRADE	YEARS	LOSS	GRADE	YEARS	LOSS
GS3	3	.5	GS9	9	.1
GS4	4	.5	GS10	10	.1
GS5	5	.4	GS11	11	.1
GS6	6	.4	GS12	12	.2
GS7	7	.3	GS13	13	.2
GS8	8	.2	GS14	14	.3
			GS15	15	.4

Figure 1. Estimated lost years of experience and percent of personnel lost during a realignment for each GS pay grade are used to calculate total lost years of experience.

b. Constraints

The best obtainable objective function values and other goals are controlled by the following constraints.

$$\sum_{f' \in NL} X_{ff'j} \leq 1 \quad \forall\, f \in NL, j \tag{1}$$

$$\sum_{f' \in NL} X_{ff'j} = 1 \quad \forall\, f \in L, j \tag{2}$$

$$\sum_{j} \sum_{e} RRES_{jer} P_{fje} \leq RES_{fr} + DEV_{fr} \quad \forall\, f \in NL, r \tag{3}$$

$$\sum_{f} \sum_{f' \in NL} \sum_{j} \sum_{t} MCOST_{tff'j} X_{ff'j} + \sum_{f \in NL} \sum_{c} CCOST_{fc} DEV_{fc} \leq MAXOTC \tag{4}$$

Equation (1) and equation (2) are movement constraints. Equation (1) ensures that no more than 100% of function j at installation f moves. This constraint allows movement only to installations that are members of the NL set. There are two versions of this constraint. The functions that can be divided when moved (administrative, maintenance) use a continuous variable. This allows the realignment of "parts" of a mission from an installation to a number of installations. The functions that are non-divisible when moved (R&D, T&E) use a binary variable.

Constraint (2) ensures facilities forced to realign are incorporated onto other installations . This constraint can be used to force a realignment by defining an installation in the model as a "L" facility. It can also be deleted from the model if forced realignments are not desirable.

The third equation ensures the required resources ($RRES_{jer}$) for the new level of personnel (P_{fje}) at an installation are available. New levels of resources for installations include: facility space for functions, housing for military, support personnel, base operations personnel, buildable acres, and utility support for water and electrical requirements. An installation's current facilities may be inadequate to support new missions and therefore, this equation is elastically satisfied (DEV_{fr}).

Equation (4) ensures the one time costs incurred for realignment are less than the total dollars available for one time costs. The sum of the movement one time costs ($MCOST_{tffrj}$) incurred for all moves (X_{ffrj}) and construction one time costs ($CCOST_{fc}$) for deviations in construction (DEV_{fc}) has to be less than the maximum one time cost (MAXOTC). This equation places a realistic constraint on realignment costs that is historically an area of limited resource.

In Chapter III the basic test model is discussed and its flexibility is demonstrated with various parameter settings.

III. COMPUTATIONAL EXPERIENCE

A. INTRODUCTION

1. Tools

This thesis uses the General Algebraic Modeling System (GAMS)[Ref. 18] and the XA solver [Ref. 19]. Computational results were collected from a 486/33 personal computer and AMDAHL 5990-500 mainframe. The information generated by any single run of the model is extensive. Appendix D contains a sample of the available information.

2. Size of the Problem

1. The model is implemented using 32 installations considered under BRAC 91 due to data availability. Installations considered and corresponding functions are listed in Appendix C. Additional installations can be added to the model when data becomes available.

2. This model considers four functions: administrative, research and development, test and evaluation, and maintenance.

3. The problems solved by this model have the following characteristics:

- there are more than 3000 positive variables,
- there are 540 binary variables,
- the model generates more than 800 constraints,
- solution times for the full model within 2% of optimality are approximately fifteen minutes on a 486/33 computer.

3. Solution Strategy

The bi-criteria model is solved using a linear weighting technique [Ref. 20]. The operating cost objective is given a weight λ, and the lost experience years objective is given a weighi $(1-\lambda)$. A composite objective is formed by adding the weighted objectives. Minimizing this composite objective with any value of λ produces an efficient solution (a solution that can not be improved in one objective without degrading the other objective). Solving for several values of λ, a plot of the efficient frontier can be constructed which represents the tradeoff between the two objective functions.

4. Model Implementing Assumptions and Data

The developed model requires extensive data to be implemented. These data are available from standard Army sources; however, these sources sometimes conflict or require interpretation before use. The following assumptions are made to show applicability and are easily changed if a different modeling strategy is considered more appropriate.

- The model uses facility information from BRAC 91 [Ref. 4]. When BRAC 91 information is not available information from RPLANS [Ref. 21] is used. BRAC data takes precedence over RPLANS when contradictions exist between the two sources.
- It is assumed all military housing is used only for military. AMC uses part of their military housing for civilians. However, there is not a consistent policy that accounts for this use.

- Installations have a limited number of buildable acres. The model uses the value for buildable acres from BRAC 91. It is assumed there are unknowns (parking, number of floors, standard size of buildings, swamps, protected areas, etc.) that may decrease the number of buildable acres; therefore, an installation with less than 50 buildable acres is not allowed to have new construction. Buildable acres has to be translated to square feet. The model uses one tenth of each acre over 50 on an installation and 43650 square feet per acre. For example, if an installation has 91 BACRES (91 - 50) 41 acres are available, which provides (41*4365) 178965 square feet for new construction.

- AMC's service and support (SaS) personnel and base operations (BASOPS) personnel requirements were identified as an area that requires further analysis [Ref. 10]. This model defines an installation's SaS personnel as the (total number of function personnel)/(existing number of SaS personnel). BASOPS personnel requirements are defined as the (total number of personnel)/(existing number of BASOPS personnel). For a complete listing of resulting base operations and support ratios see Appendix C.

- The model determines the shortage of required water, sewer, and electric resources. RPLANS [Ref. 21] provides the required facility information and the amount of resource required on an installation per person. Using this information, a shortage of required utility support for present personnel levels at some installations is evident. Instead of changing the established resource figures to reflect the inconsistency in the data, shortages are reported and construction cost is included for any shortfall.

- T&E missions are diverse throughout AMC. T&E missions can only move to an installation that has administrative space for T&E personnel and test sites that are larger than the current location.

- Maintenance capacity used for BRAC 91 [Ref. 4] is listed in man-hours. Utilization rates are determined using man-hour data. The same rate is used to determine utilization in space (square feet)(see Appendix A for an example).

B. TEST PROBLEMS

Throughout the modeling phase of this thesis parameter values were determined, estimating relationships were developed, and data manipulations conducted to ensure a realistic model. The resulting model is referred to as the "basic model". Using the basic model, sensitivity analysis was conducted to show the effects of different parameters on realignment. Results of five representative variations of the basic model are presented.

The efficient frontier represents the most efficient alternatives between operating cost and lost experience years. Each point on the curve has an associated set of function realignments. The basic model curve in Figure 2 shows the current operating cost of $1.68 billion to a minimum operating cost of nearly $1.49 billion and over 53,000 lost experience years. The one time costs associated with recommended realignments assists in determining the payback period and breakeven points. Figure 3 depicts the one time costs for transportation, construction, and hiring against associated operating costs for the basic model.

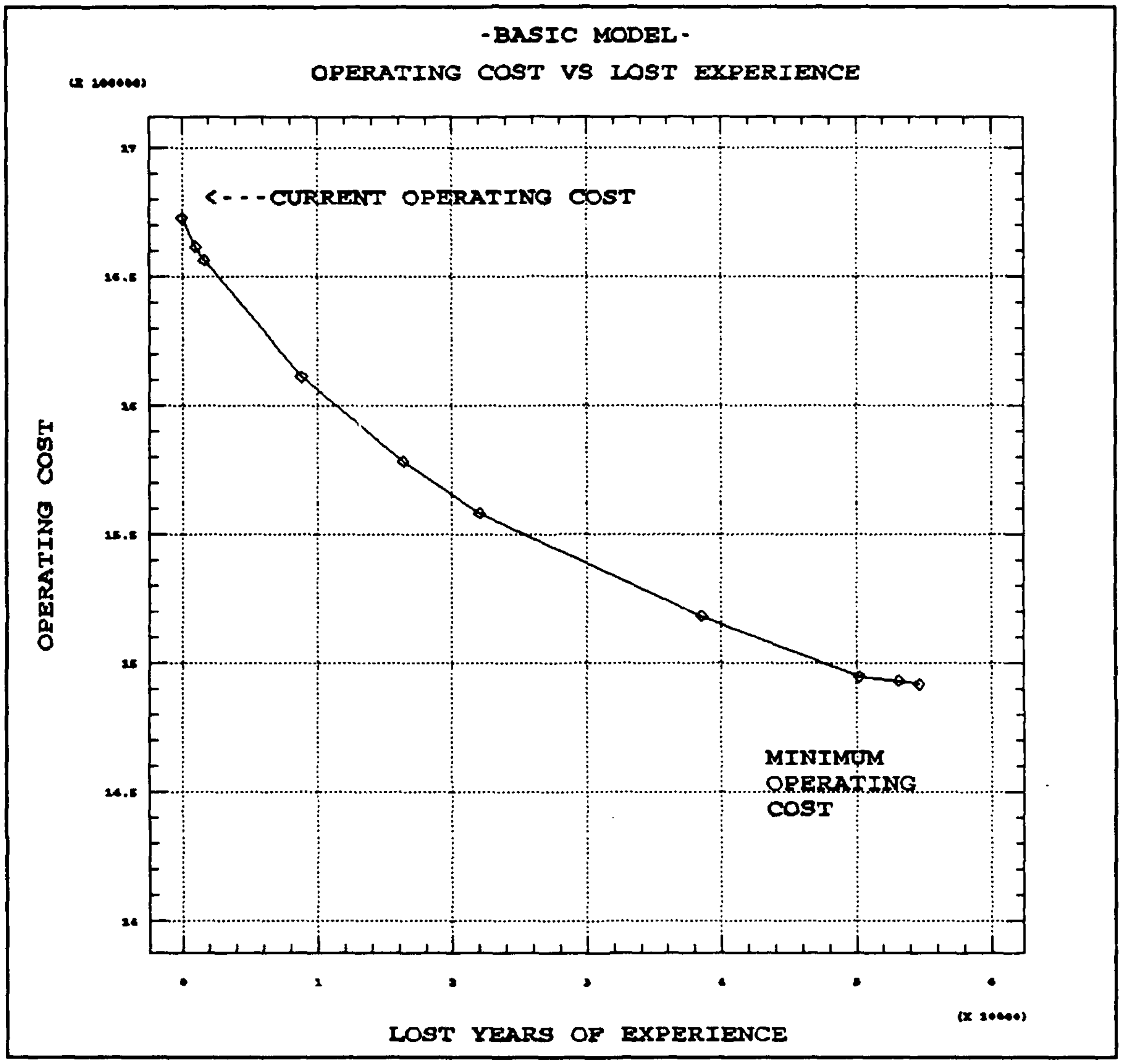

Figure 2. The basic model's efficient frontier illustrates tradeoffs and marginal improvements between different linear combinations of the objective functions.

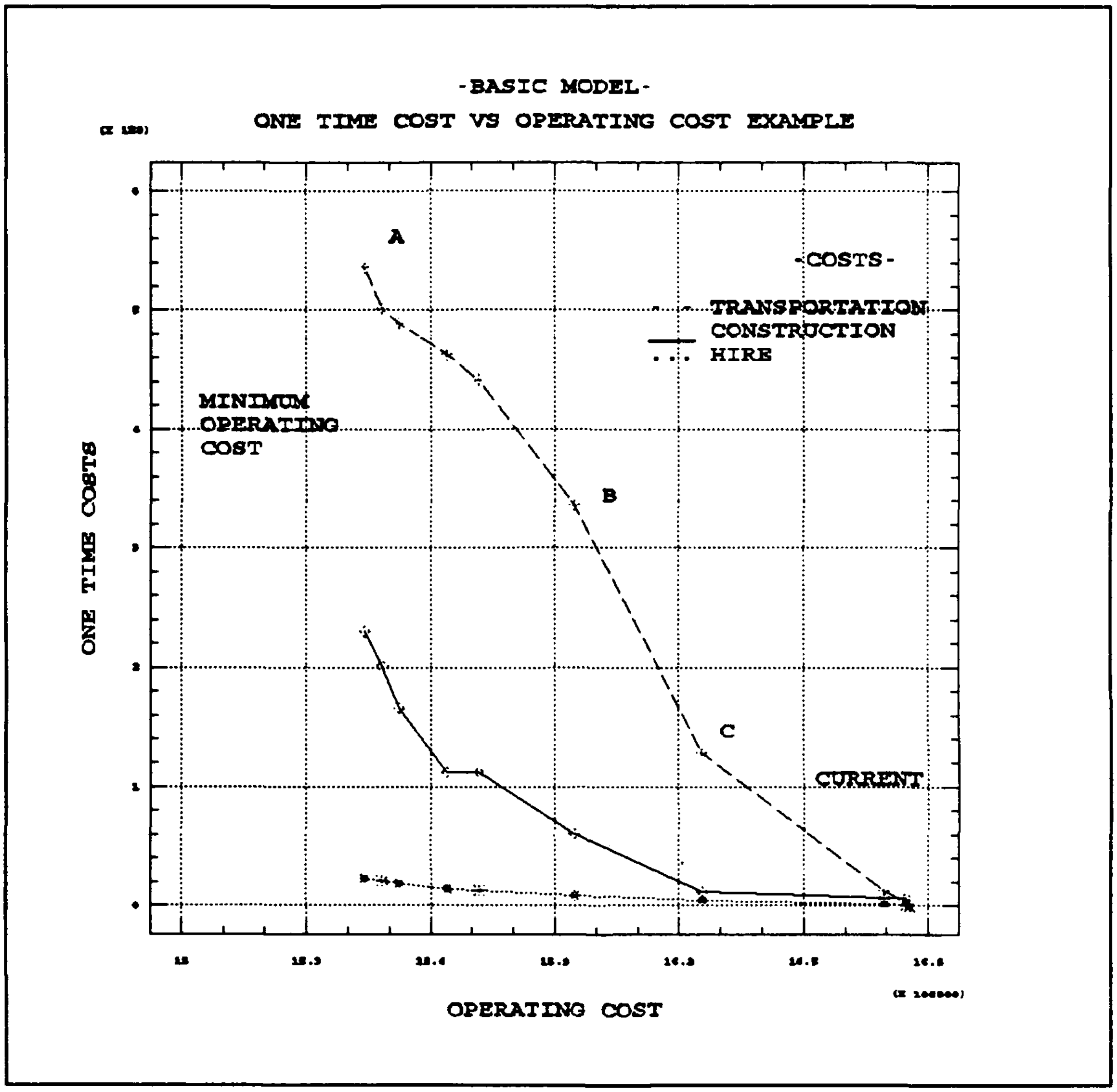

Figure 3. The model captures the one time costs for transportation, construction, and hiring. Marginal savings differ between realignment alternatives that will effect payback periods.

Figure 3 demonstrates considerable savings for a small OTC at point C with a significant OTC increase from point C to A. The curve provides insight into the fact that alternative realignments have different marginal savings in operating cost. Figure 4 expands these results at the three points highlighted on Figure 3. At point

A, realignment requires 2.48 dollars for each yearly dollar saved. Point C has increased yearly savings but it requires a OTC of 4.03 dollars for each yearly dollar saved.

FACTOR CONSIDERED	POINT A	POINT B	POINT C
OPERATING COST	1,578,391	1,558,349	1,492,020
OPERATING COST SAVINGS	94,600	114,606	180,970
ONE TIME COSTS (OTC)	234,673	354,630	731,085
OTC PER DOLLAR SAVED	2.48	3.09	4.03

Figure 4. From points A to C, an increase in OTC provides increased savings and lower operating cost. However, the cost per dollar saved increases.

1. Test Problems Considered

The basic model's parameters are manipulated and additional computations at the new parameter setting completed. Test problems considered are:

- The basic model does not force (FORCE) any functions to realign. The test model adds a forced function realignment.
- Any construction that takes place requires buildable acres (BACRES). Changes in the calculation that determines maximum area available for BACRES may effect model results. This test model determines the effect.
- Vision 2000 analysis identified civilian salary as a main driver behind realignment scenarios [Ref. 7]. Average civilian salary is manipulated (ACS) to determine its effect. The basic model uses the gaining installations average civilian salary for personnel realigned. In the ACS variation to the basic model personnel moved maintain the ACS of their original installation.
- One time costs effect on realignment is tested (OTC).

Figure 5 lists the test problems with changed parameter highlighted. Each row of Figure 5 represents a different test problem with the top row being the basic model. An efficient frontier is generated for each test problem and compared to the basic model.

VARIATION	OTC	FORCE	ACS	BACRES
BASIC MODEL	$1.0 BILLION	NO	GAINING	LIMITED
$.50 BILLION BUDGET	$.50 BILLION	NO	GAINING	LIMITED
$.25 BILLION BUDGET	$.25 BILLION	NO	GAINING	LIMITED
FORCE A REALIGNMENT	$1.0 BILLION	YES	GAINING	LIMITED
SALARY CHANGE	$1.0 BILLION	NO	LOSING	LIMITED
UNLIMITED ACRES	$1.0 BILLION	NO	GAINING	UNLIMITED

Figure 5. Each row in this matrix represents a test model. The first model is the basic model. The six model variations are tested to determine the changing parameter's effect on realignment.

2. Tests

a. Forced Realignments

Consider the realignment of a facility in St. Louis onto permanent installations. The efficient frontier generated by this test problem is superimposed on the basic frontier and illustrated in Figure 6.

The effect of a nonoptimal action is easily seen on Figure 6 where operating cost is always at least $12 million more than the minimum possible. The minimum operating cost for the basic model solution is approximately $1.492 billion while the forced realignment test model's is $1.504 billion. This forced realignment action uses needed one time resources which stops other potential realignments from taking place.

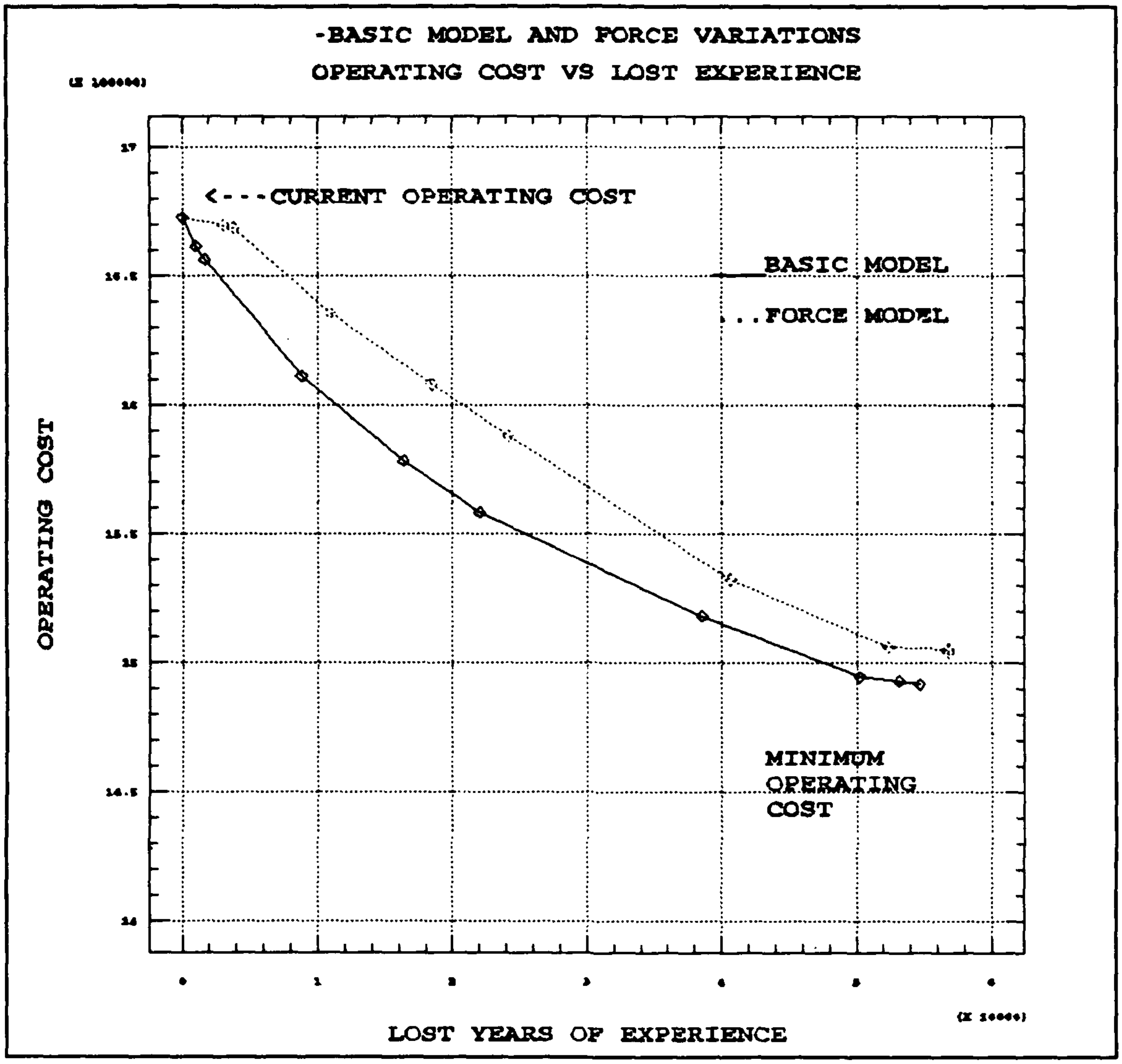

Figure 6. A forced realignment will effect model results if it is not recommended for realignment otherwise. The effect of a nonoptimal action is demonstrated above.

b. Maximum Buildable Acres

The basic model's BACRE constraint is changed in this test model to see if limiting acreage effects realignment. The test model uses the BRAC 91 [Ref. 4] value as the available number of BACRES at an installation versus the basic model's more restricted BACRE rule (1/10th of BRAC 91 greater than 50). The efficient frontier generated by this test problem is superimposed on the basic frontier and illustrated in Figure 7.

The tightness of the fit between the two models implies little effect on model results when the BACRE parameter is changed. This implies that BACRES is not a restrictive factor in the model and either condition would be a reasonable estimate.

c. Average Civilian Salary Rule

The efficient frontier generated by the two variations in ACS is superimposed on the basic frontier and illustrated in Figure 8. If a realigned function's personnel maintain their losing installations average salary there is an insignificant decrease in the minimum operating cost of $1.09 million. This result implies that average civilian salary has a minimal affect on final costs. Further analysis shows ACS does not affect the realignments that consistently take place during the basic and ACS test problems. Therefore, either salary rule can be used with minimum effect on persistent realignment and only a slight effect on general results.

d. One Time Costs

Realignment is restricted by available dollars for OTC. Vision 2000 generated a one time cost of approximately $2.0 billion [Ref. 1]. OTC of $1.0 billion,

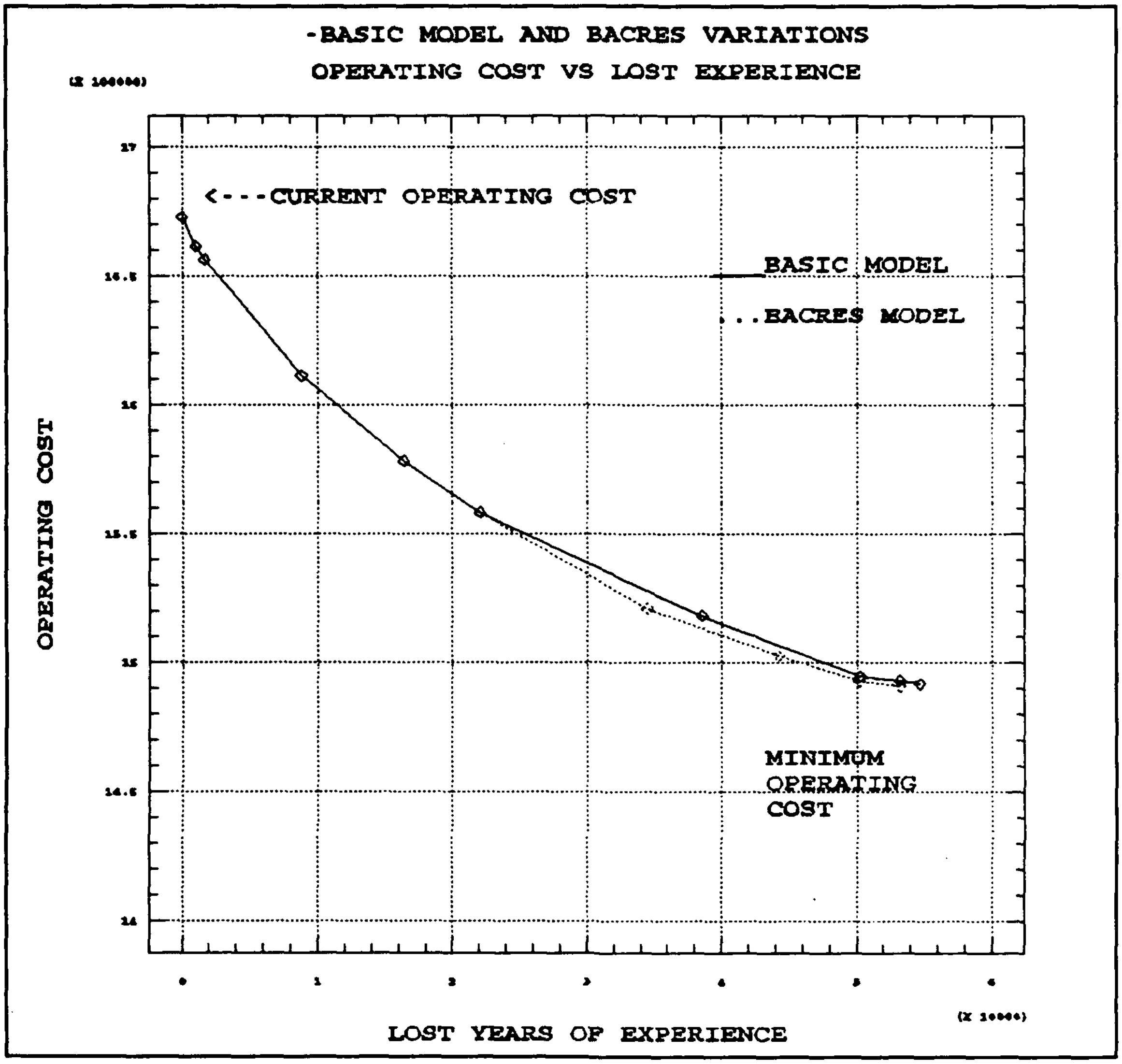

Figure 7. The two variations in BACRES parameter considered have little effect on model results.

$.5 billion, and $.25 billion are tested. The basic model uses $1.0 billion or 1/2 of the Vision 2000 figure since the model does not consider all AMC functions.

Figure 9 illustrates efficient frontiers generated by different OTC values for the basic model. There is a significant difference in savings potential between OTCs of $.25 billion, $.5 billion, and $1.0 billion dollars. In this scenario

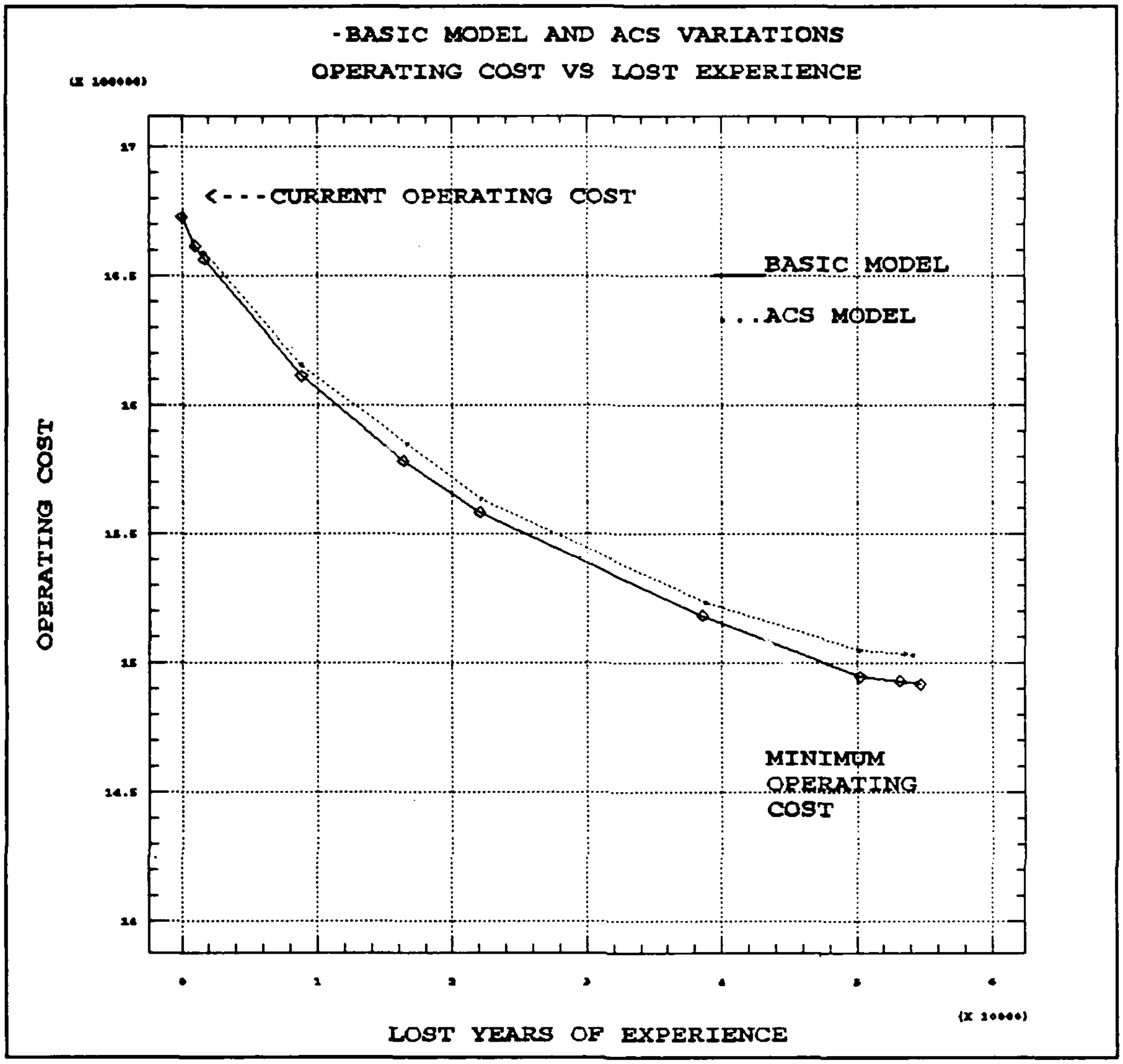

Figure 8. ACS effects operating cost to a small extent. Either ACS rule can be used with similar results.

the different OTCs resulted in operating cost savings of approximately \$98.4, \$153.7, and \$181 million. These savings equate to a marginal cost of \$2.54, \$3.25, and \$4.03, respectively, for each dollar saved.

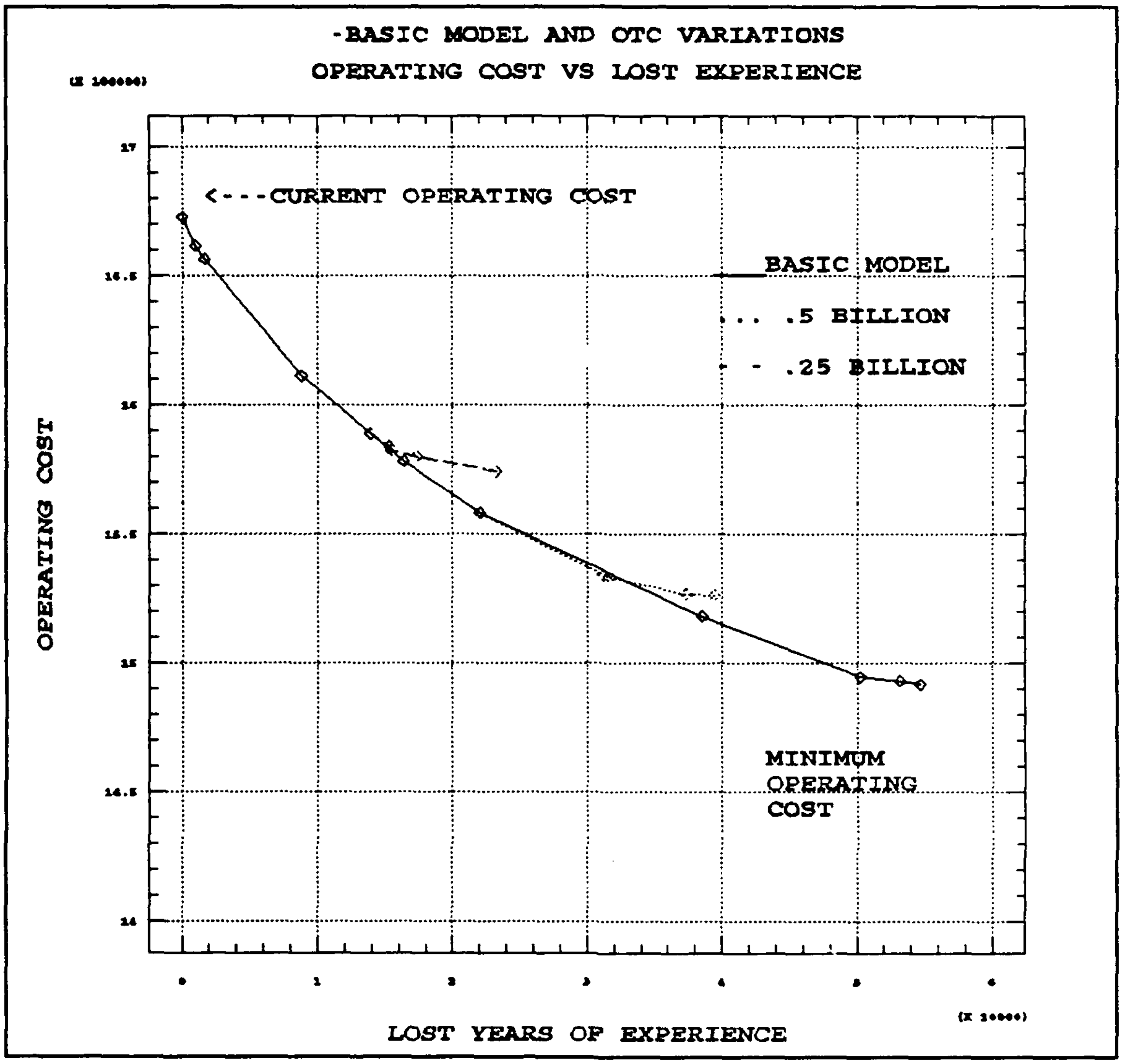

Figure 9. The available OTC has an effect on the operating cost savings. More OTC dollars allows an increased number of realignments and results in increased savings in operating cost.

C. RESULTS

The purpose stated for this thesis was to develop an optimization model to assist AMC in future decisions on BRAC recommendations. The model demonstrates that the optimization approach is a viable technique to augment analysis for BRAC decisions. Of particular interest are the function realignments that consistently take place using different test models. Figure 10 contains the realignments for the R&D function at minimum operating cost (no consideration for lost experience years and no limitations on where a function can realign). The model produces similar results for all functions.

FROM	TO	OTC $1.0	OTC $0.5	OTC $.25	FORCE	ACS	BACRES
RRAD	TOAD	1	1	1	1	1	1
SVAD	TOAD	1	1	1	1	1	1
FTM	TOAD				1		
PTA	TOAD	1				1	1
	RSA				1		
RIA	RSA	1					
	APG				1	1	1

Figure 10. R&D realignments that take place when lost experience years is not considered. For example, a (1) for RRAD to TOAD under OTC MAX means the Red River R&D function moved to Tobyhanna in the model run for the OTC MAX test model. Installation codes used in Figure 10 are: APG-Aberdeen, RIA-Rock Island, PTA-Picatinny, TOAD-Tobyhanna, RSA-Redstone, FTM-FT Monmouth, SVAD-Savanna, and RRAD-Red River.

As the lost experience years objective is given more importance (a greater weight), less realignments take place. Intuitively this is correct because if minimizing the lost experience years is seen as the most important objective, zero moves take place. The persistent realignment for R&D when operating cost is considered but the lost experience years objective is heavily weighted is the move from Savanna to Tobyhanna.

Chapter IV discusses possible uses of the tools described in this chapter, areas for expansion, and applications for AMC.

IV. CONCLUSIONS

A. POSSIBLE USES OF THE MODEL

The computational experience reported in Chapter III highlights the insight that can be gained from the derived model. The model and corresponding insight can assist AMC in their analysis of alternatives for future installation realignment and closure actions.

1. An Analysts' Tool

The model provides a quick tool to analyze different courses of action. The full model will solve test problems guaranteed within 2% of optimal in approximately 15 minutes or to guaranteed optimality within two hours on a personnel computer. Small test models forcing a move to take place will solve to guaranteed optimality in less than two minutes.

2. Closings

A test model forces realignment of a leased facility into permanent facilities. This is only one example to demonstrate the model's capabilities. Other facilities could be forced to realign and various alternatives for closing that "have to" take place could be easily evaluated. It is also possible to specify both the realigned installation and the gaining installation to evaluate the effect.

3. Mandatory Decreases in Workforce

The computational results in Chapter III reports all results assuming that current personnel levels will be maintained. This level was chosen due to lack of information on which functions would reduce. The real power of the model rests in its ability to determine the "optimal" realignment for any future personnel level. Given varied personnel figures, the model could be run several times and the optimal realignments and closures under various levels compared.

4. Effects of Parameters

The model allows the manipulation of numerous parameters and the analysis of its effect. For example, the buildable acre parameter was suspected of being restrictive in determining realignments. The test model shows buildable acres is not a restricting parameter and therefore, either measuring technique tested could be used.

5. Tradeoffs

The model provides tradeoff results in personnel, construction, housing, transportation, and cost areas.

The efficient frontier developed from model results demonstrated tradeoffs between operating cost and lost experience years. The efficient frontier could be used as a tool to determine the marginal savings in cost for the loss of experience incurred. Other tradeoffs are examined graphically by plotting alternative values of different characteristics and analyzing the results. Figure 11 illustrates the number of personnel moved and personnel lost for alternative realignments at different levels of operating cost.

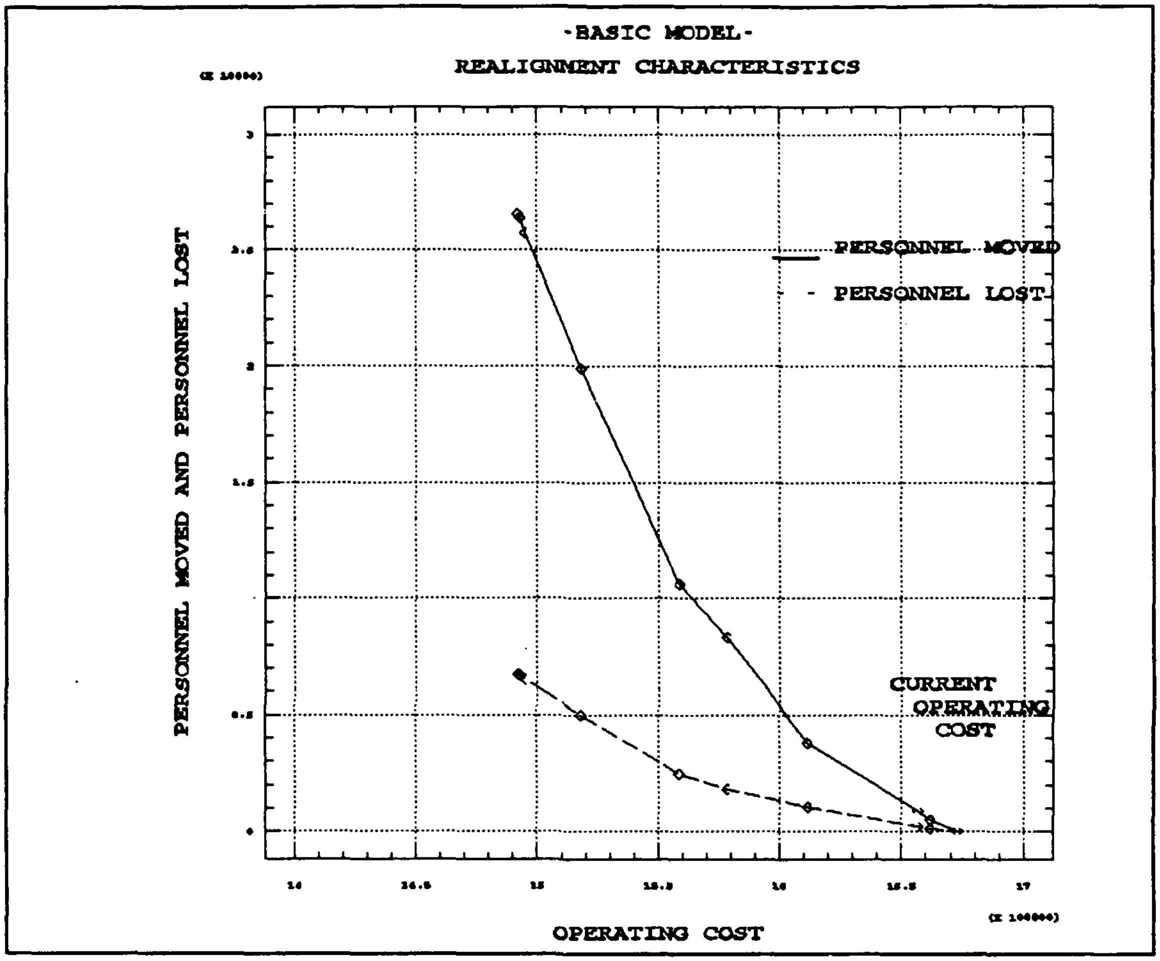

Figure 11. Model characteristics can be plotted for analysis. The personnel moved and personnel lost characteristics give a feel for the number of people effected during realignment.

Other characteristics could be easily plotted for analysis and additional insight into realignment effects.

B. EXPANSION

1. Data

The model is limited by the amount and quality of data readily available for analysis. The first area that could be expanded is the model's data base. This includes the data for future personnel levels and supply and production functions not considered in this thesis.

2. Distribution Problems

Of particular interest to the author is a classic operations research problem for consolidation of AMC supply, warehouses, and ammo storage facilities. This problem is similar in basic structure to this thesis.

APPENDIX A

Data is distributed into three categories. Fixed data are those that contribute to the operating costs and are independent of the missions or number of personnel on an installation. Variable data are dependent on the new personnel level. And third, data are provided by the model user as restrictions on resources.

The majority of data is considered adequate to demonstrate the applicability of this modeling approach. However, some data are inconsistent between sources, missing, or inaccurate. Such data are duly noted.

The major sources of data are:

- BRAC Report - The Base Realignment and Closure report includes the majority of data for the military attributes included in the model.
- RPLANS - The Real Property Planning and Analysis System has numerous cost, facility, and personnel factors.
- AMC-sx - The special analyst group at AMC provided information on housing, leased facilities, personnel, and institutional knowledge on the operations of AMC.

A. BRAC

The Base Realignment and Closure process used to implement recommendations in 1991 included five broad categories referred to as measures of merit on which the "military value" of an installation was derived. Each measure of merit was composed of several attributes which differed depending on the type of installation (depot, commodity, production). Due to the emphasis placed on the measures of merit, efforts are taken to include them in the model. The model includes the following characteristics for installations types noted in parenthesis.

1. Mission Essentiality

Maintenance Capacity is a measure of manhours available for maintenance at an installation. This factor was used to develop the depot maintenance excess space capacity in square feet, SF. For example, Anniston has a maintenance capacity of 3,925,000 manhours and unused capacity of 715,000 or 18.2%. Anniston also has maintenance space of 1,293,000 SF. Using the manhour unused rate of 18.2% equates to an unused capacity of 235,326 SF.

2. Mission Suitability

- Administrative Facilities is a measure of the available facilities used for administrative missions on an installation. Unit of measure is square feet (depot,commodity).
- Research and Development Facilities is a measure of the facilities used in the support of materiel development available at an installation. Unit of measure is square feet (commodity).
- Test Ranges/Sites is a measure of the range capacity and/or condition to support live fire events at an installation (commodity).

3. Mission Essentiality

- Variable Housing Allowance is self-explanatory. Unit of measure is dollars (depot, commodity, production).

- Army Family Housing Costs Per Dwelling Unit is a measure of the cost to maintain one set of family quarters of an installation. Unit of measure is dollars (depot, commodity, production).

- Average Civilian Salary is self-explanatory. Unit of measure is dollars per year (depot, commodity, production).

- Utilities Cost Factor is a measure of the per capita cost of utilities at an installation. The unit of measure is dollars (depot, commodity, production).

- Real Property Maintenance Cost Factor is a measure of the average cost to maintain 1000 square feet of real property. Unit of measure is dollars per 1000 square feet (depot, commodity, production).

- Military Construction Cost Factor is the relative cost factor for construction at an installation. Measure is an indexed value (depot, commodity, production).

4. Expandability

- Total Buildable Acres is the acreage available for construction of additional facilities at an installation. Unit of measure is acres (depot, commodity, production).

- Total Unused Administrative Buildings is the square footage of administrative facilities currently unused at an installation. Unit of measure is square feet (depot, commodity, production).

- Total Unused Research and Development Buildings is the square footage of laboratories and other research facilities currently unused at an installation. Unit of measure is square feet (commodity).

5. Quality of Life

There are three Quality of Life factors used in the model which are in the housing category. These characteristics are a measure of housing units available for families and unaccompanied military personnel. The unit of measure is number of housing units (depot, commodity, production).

B. RPLANS

The Real Property Planning and Analysis System (RPLANS) is an automated real property management tool. AMC provided the required interface. RPLANS was used to augment data available from BRAC. The following is a description of data used.

1. Maintenance Capacity

These data are a measure of the maintenance facilities available at an installation. Unit of measure is square feet. A combination of four facility category groups (FCG) provide the capacity value for required facilities.

- 21410 Organizational Maintenance,
- 21420 Direct/General Support Vehicle Maintenance Shop,
- 21610 Ammo Maintenance Building,
- 21800 Special Purpose Maintenance Shop.

2. Water/Sewer Capacity

These data are a measure of available water and sewer resources at an installation. Four areas of water and sewer requirements were defined in the model.

- 83200 Sewage and Industrial Waste Collection (linear feet),
- 84200 Water Distribution System (linear feet),
- 84100 Water Supply and Treatment (Kgal),
- 83100 Sewage and Industrial Waste Treatment and Disposal (Kgal).

3. Electric Capacity

These data are a measure of available electric resources at an installation. Two areas of electrical requirements were defined in the model.

- 81100 Electric Power Source (Kvolts),
- 81200 Electric Transmission (linear feet).

4. Administrative Capacity

There are data for administrative capacity in BRAC for Commodity installations. RPLANS provides the capacity for depot and production capacities. FCG 61050 - Administrative Facilities (SF) is used.

C. AMC-SX

AMC offices provided information on: leased facilities, personnel per installation, personnel per grade, and personnel per function area [Ref. 22]. AMC also provided articles, policy letters, and insight into AMC's operations.

APPENDIX B

Appendix B describes model equations and their parameters. The discussion of complicated equations includes examples to improve understanding.

A. OBJECTIVES

1. Minimize Operating Cost

$$\sum_f \Big(\sum_e \Big(\Big(\sum_j VC_{fe} P_{fje}\Big) + \Big(\sum_h VHA_{fe} DEV_{fh}\Big)\Big) + \Big(\sum_s RPMA_f DEV_{fs}\Big) + FC_f\Big)$$

a. $VC_{fe}P_{fje}$

The variable costs (VC) associated with any realignment is a combination of the following factors:

- the average civilian salary: civilian salary costs at an installation [Ref. 4],
- and the utility cost factor per person: a measure of the per capita cost of utilities at an installation [Ref. 4].

Example: Anniston has an average civilian salary of $29,078 and a utility cost per person of $1412.35. Therefore, the cost for one civilian employee at Anniston is $30,490.35 ($29,078 + $1412.35). Other costs associated with each employee (eg. costs of supporting personnel) are captured elsewhere in the model.

b. $RPMA_f DEV_{fs}$

The Real Property Maintenance (RPMA) cost factor for buildings is a measure of the average cost to maintain 1000 square feet of real property [Ref. 4]. RPMA variable costs are dependent on the new construction required on an installation (the RPMA for existing facilities is included in the fixed cost of an installation). The value for deviations in capacities (DEV_{fs}) at an installation are determined using constraint (3).

$$\sum_f RPMA_f \quad \sum_s DEV_{fs} \quad = RPMA$$

Example: Red River has a RPMA cost of $1048.37 per 1000 square feet of building space. If Savanna's R&D mission moves to Red River, there is a new construction requirement for 4000 square feet. This additional space requires an additional RPMA cost of $4193.48 ($1048.37*4) at Red River.

c. $VHA_e DEV_{fh}$

Variable Housing Allowance (VHA) is required for military without government housing [Ref. 23]. The cost is the product of the VHA cost and any military personnel that can not be housed in military housing. Any deviation from required and provided housing is determined by constraint (3).

d. FC_f

The fixed cost (FC_f) at installation f is a sum of these factors:

- the housing maintenance costs: maintenance costs per housing unit at an installation [Ref. 4],

- the combination of variable costs for all personnel that are "fixed" on the installation (not considered for realignment),

- and RPMA cost for existing facilities.

Example: The fixed cost at Anniston is $41,938,148, which includes: a housing maintenance costs of $37,715 (5*$7543), a variable cost for production and supply personnel of $39,484,550 (1295*$30,490), and a RPMA cost for existing facilities of $2,415,883.20 ($726.80*3,324).

2. Minimize Lost Experience Years

$$\sum_{f} \sum_{f' \in nl} \sum_{j} YL_{fj} X_{ff'j}$$

The lost experience years objective determines the lost years of personnel experience in man-years estimated from any realignment. The single term in this objective, $YL_{fj}X_{ff'j}$, represents the lost years (YL) summed for all grades of civilian in missions j moved from installation f.

Example: If Savanna's R&D mission with 79 civilians is realigned the lost experience years is determined using information in Figure 12. The results depicted in Figure 12 are realized with the two methods previously considered to calculate lost experience years.

GRADE	YEARS	PERS	%LOST METHOD 1	PERS* %LOST	YEARS*PERS *%LOST
GS3	3	2	.5	1.0	3.0
GS4	4	6	.5	3.0	12.0
GS5	5	13	.4	5.2	32.5
GS6	6	27	.4	10.8	64.8
GS7	7	10	.3	3.0	21.0
GS8	8	6	.2	1.2	9.6
GS9	9	1	.1	0.1	.9
GS10	10	3	.1	0.3	3.0
GS11	11	9	.1	0.9	9.9
GS12	12	1	.2	0.2	2.4
GS13	13	1	.2	0.2	2.6
TOTAL		79	--------	25.9	161.7

Figure 12. Method 1 values above result in a loss of 25.9 personnel (32.7%) and 161.7 lost years. Using the standard Army factor of 28.7% (Method 2) results in a loss of 22.7 personnel and 154.406 lost years.

The lost personnel and lost years for the standard army factor method is slightly different from the proposed Method 1. Using the other method proposed in this thesis results in a loss of 28.7% and 22.7 personnel.

B. CONSTRAINTS

The objective function values and other mentioned goals are controlled by the following constraints.

$$\sum_{f'} X_{ff'j} \leq 1 \quad \forall\, f \in NLj \tag{1}$$

$$\sum_{f'} X_{ff'j} = 1 \quad \forall\, f \in Lj \tag{2}$$

$$\sum_j \sum_e RRES_{jer} P_{fje} \leq RES_{fr} + DEV_{fr} \quad \forall f \in NL, r \tag{3}$$

$$\begin{gathered}\sum_f \sum_{f' \in NL} \sum_j \sum_t MCOST_{tff'j} X_{ff'j} \\ \sum_{f \in NL} \sum_c CCOST_{fc} DEV_{fc} \leq MAXOTC\end{gathered} \tag{4}$$

1. Constraints (1) and (2)

Constraints (1) and (2) are discussed in Chapter II.

2. Constraint (3)

Constraint (3) ensures required resources for realignment personnel levels are available at installations. Any deviations from available resources are satisfied elastically (DEV_{fr}).

Captured in this constraint are the deviations for the following resources:

- space (in square feet) required and deviations for administrative, research and development, and depot maintenance functions,
- requirements and deviations (per person) for utilities (water, sewer, electric),
- and housing required and deviations for military families, accompanied and unaccompanied military personnel.

Each resource's required parameters and explanatory equations are discussed below.

a. Space

Functions require space to conduct activities. Two methods of determining required space are used in the model. The administrative and T&E functions use a standard factor approach. Each new person requires 162 square feet of space [Ref. 21]. The R&D and depot maintenance functions use a one-for-one approach. If one of these functions are moved then a like amount of space is required at the gaining installation. This approach is appropriate due to the diversity in R&D and maintenance functions.

Administrative space capacity information is found in BRAC 91 data [Ref. 4]. Some installation information is not available in BRAC 91 data. In these cases RPLANS data [Ref. 21] are used. RPLANS does not provide an unused rate; therefore, space from RPLANS is given a 3% unused rate (approximately the largest unused rate).

The administrative space equation accounts for administrative missions, T&E, and administrative leased space requirements.

$$\left(\sum_{f'} \sum_{e} PERS_{f'je} X_{f'fj} - \sum_{f' \in NL} \sum_{e} PERS_{fje} X_{ff'j}\right) RRES_{js}$$
$$= RES_{fs} + DEV_{fs} \quad \forall\, f,\ j=admin,\ s=admin$$

Example: Anniston has a total of 602,000 SF and 18,060 SF of unused space (RES_{fs}). If Picatinny's 164 administrative personnel ($PERS_{f'je}$) are realigned to Anniston and Anniston's personnel do not move there is an increased need of 8508 additional SF as calculated below.

$$((164*1)-(PERS_{fje}*0))*162 = 18{,}060 + 8508$$

The maintenance and research equation differs from the administrative equation because it ensures new functions have the same space available at the gaining installation.

$$\sum_{f'} RES_{f's} X_{f'fj} + \sum_{f' \in NL} RRES_{fs}(1 - X_{ff'j}) = RES_{fs} + DEV_{fs}$$
$$\forall\ fj = maint,\ s = maint$$

A maintenance function requires the same amount of space at its new location. Unused space can be used by a new mission.

Example: If Letterkenny's maintenance mission (used space = $RES_{f's}$ = 732,910 SF) is realigned to Tobyhanna (used space = $RRES_{fs}$ = 593,900 SF), Tobyhanna (total of 857,000 SF) will require an additional 469,810 SF of maintenance space.

$$732{,}910*1 + 593{,}900*(1-0) = 857{,}000 + 469{,}810$$

Deviations in space are used to determine construction costs in constraint (4) and RPMA costs in the operating cost objective.

b. Utilities

Constraint (3) determines the deviations in the capacity of water and electric utility support. Requirements per person for utilities and an installation's available support are in RPLANS [Ref. 21]. The same equation is used for both water and electric utilities by replacing appropriate constants.

$$\sum_j \sum_e P_{fje} RRES_{jer} = RES_{fr} + DEV_{fr}$$
$$\forall\ f,r \in water, electric$$

Example: if Anniston's maintenance mission (P_{fje} = 3344) is realigned to Letterkenny (capacity of 92000 linear feet of water collection), an additional 15008 linear feet (RRES = 32 linear feet per person) of water collection ability will be required ((3344*32) = 92000 + 15008).

Figure 13 has the utility Facility Category Group codes (FCG) used in the model and the requirement per person on a base for each code [Ref. 21]. The model determines the deviations in requirements for personnel only and therefore excludes industrial requirements or contracts.

FCG	DESCRIPTION	FACTOR
83100	Sewage treatment in thousands of gallons per day (Kgal).	0.19
83200	Water and sewer collection in linear feet (LF).	32
84100	Water treatment and supply in Kgal per day.	0.28
84200	Water and sewer distribution in LF.	43
81100	Electrical power source in Kvolts.	1.4
81200	Electrical transmission in LF.	108

Figure 13. The required utility support per person (FACTOR) for the different utility categories (FCG) considered in the model are listed above.

c. *Housing*

The number of military housing units available at an installation in family, unaccompanied officer, and unaccompanied enlisted categories is from BRAC 91 data. The housing constraints utilize standard factors [Ref. 17] for the percent of enlisted and officers that are eligible for housing (PH_e) and that are acompanied or unaccompanied.

$$PH_e \sum_j P_{fje} = RES_{fh} + DEV_{fh} \quad \forall f,e \in military$$

Example: If the Aberdeen Proving Ground's R&D function is moved, 44 (P_{fje}) officer positions are moved of which 30% are accompanied. If realigned to Savanna (31 family units $=RES_{fh}$) 54% are eligible for family housing and an additional 15.54 units are required. Values for personnel levels and percent authorized are estimates and therefore fractional quantities are used.

$$0.54*(44+2 \text{ Savanna officers}) = 0.3*31 + 15.54$$

1. Constraint (4)

Constraint (4) ensures all one time immediately incurred costs do not exceed model limits. Captured in this constraint are the following costs:

- the costs to hire new personnel (MAXH),
- transportation costs for realignments (MAXT),
- and construction costs for required function space (MAXC).

Each cost parameter and explanatory equations are listed below.

a. Hire Costs

Hiring cost to maintain pre-realignment personnel levels depends on the number of personnel that are lost during a realignment. The hiring cost for any function on an installation depends on the predicted percent of personnel lost for each grade and the number of personnel in the grade. The standard factor of $5000.00 [Ref. 17] is used for this cost in the following equation.

$$\sum_f \sum_j 5000(PL_{fj}) = \text{Hiring Cost}$$

Example: Consider the realignment of Savanna's R&D mission with 79 civilians. Figure 12 illustrates the calculations that determine the number of lost personnel (PL_{fj}) for this realignment. Using the lost personnel figure from this example (22.67), the hire cost is calculated as $113,350 (5000*22.67).

b. Transportation

Transportation costs depend on the number of personnel that are realigned and is a combination of :

- housing support costs for civilians,
- personnel travel,
- movement of personal vehicles,
- shipping and packing of household goods,
- and costs to transport administrative weight.

Cost estimating relationships from COBRA [Ref. 6] are used to estimate transportation costs. Derived variables and parameters used to determine transportation costs are listed in Figure 14. Parameters listed in Figure 14 that are given a value of TABLE have a different value for each installation.

DESCRIPTION OF VARIABLE	SYMBOL	VALUE
Civilian Personnel moved	P	VARIABLE
DESCRIPTION OF PARAMETER	SYMBOL	VALUE
Distances between installations [Ref. 24]	DIST	TABLE
Cost of air transportation per mile [Ref. 17]	MA	.12
Per-diem costs at an installation [Ref. 23]	PD	TABLE
Homeowners rate [Ref. 17]	HR	64%
Average house price [Ref. 17]	AHP	96800
Home sale Reimbursement Percent [Ref. 17]	HSRR	10%
Home purchase Reimbursement Percent [Ref. 17]	HPRR	5%
Cost Factor for area [Ref. 17]	CF	TABLE
Miscellaneous travel cost [Ref. 17]	MISC	$700
Cost to transport private vehicles [Ref. 17]	MV	$.23
Administrative weight per person [Ref. 17]	ADWT	710
Packing and transport for HHG per 100 lbs [Ref. 25]	PT	$62.46
Cost to ship freight, dollar per mile per ton [Ref. 25]	MF	$.0578
Personnel household goods for realignment [Ref. 17]	HHG	TABLE

Figure 14. Data to determine the transportation cost of moving personnel and sources are listed above. The word TABLE is used to indicate a different value for each installation or pair of installations.

For example, the total travel cost to realign 10 civilian employees from Anniston to Bluegrass is $185,217 (costs to transport equipment and military vehicles are not considered). A breakdown of the equations that generate these costs follows.

(1) Housing Assistance

Housing support includes house hunting and housing assistance costs and is determined for one mission moving between two installations using the following equation:

$$P_{ff'}((4 \cdot DIST_{FF'} \, MA) + (8.75 \cdot PD_{f'}) + (HR \cdot AHP \cdot CF_{f'} \cdot HSRR) + (HR \cdot AHP \cdot CF_{f'} \cdot HPRR))$$

Values for parameters in this equation are included in Figure 14 or in one of the model's data tables.

Example: The cost for housing assistance for 10 civilians realigned from Anniston to Blue Grass is: $109,155.24.

$$10(4*410*.12+8.75*78+(.64*96800*1.08*.1)+.64*96800*1.08*.05)$$

(2) Personnel Travel

Travel of realigned personnel includes costs to transport privately owned vehicles, administrative weight per person, and miscellaneous travel costs. Personnel travel is determined for one mission moving between two installations using the following equation:

Example: The cost to relocate 10 employees for personnel travel from Anniston to Blue Grass is: \$32,340.

$$10(700+78(30+(410/350))+(410*.23)+((710/2000)*410*.0578))$$

(3) Household Goods

Cost for movement of household goods (HHG) includes packing and shipping costs. Standard factors for weight authorizations (HHG) in pounds are used (7000 for officers, 4000 for enlisted, and 7000 for civilians). Factors are combined to determine hire cost in the following equation:

$$\sum_f \sum_{f'} \sum_j \sum_e P_{ff'je}(PT \cdot HHG_e)$$

Example: If the 10 civilians are moved from Anniston to Blue Grass 70,000 lbs of goods have to be packed and transported. The cost to move these goods is \$43,722 (10*7000*.6246).

c. Construction

Deviations in space and utility requirements are determined by constraint (3) and used in constraint (4). The OTC incurred for this deviation (DEV_{fC}) is a combination of costs for function space and utilities ($CCOST_c$). Costs for missions are standard factors [Ref. 17]. The costs for utilities are estimates [Ref. 26]. The following equation determines the total construction cost.

$$\sum_f \sum_c CCOST_{fc} DEV_{fc} = MAXC$$

Example: Suppose all construction requirements are met except for the needs of the new mission of Letterkenny's maintenance mission to Tobyhanna. The resulting 469,810 SF shortage requires $70,697,008 (1.14*$132*469810, where 1.14 is the construction cost factor for Tobyhanna, and 132 is dollars per SF).

d. Maximum One Time Cost

The maximum OTC incurred for realignment can be varied. In Chapter III, models using $1.0 billion, $500 million, and $250 million were discussed. The OTC is a combination of the hire (MAXH), transportation (MAXT), and construction (MAXC) costs defined in this Appendix.

$$MAXH + MAXT + MAXC = MAXOTC$$

APPENDIX C

The model considers 32 AMC installations for realignment. Installations and their corresponding functions are listed in Figure 15.

An installation has service and support (SaS) personnel and base operations (BASOPS) personnel required to operate and maintain the installation. Present ability to measure the required levels of personnel is limited [Ref. 10]. The model uses a linear relationship to determine a ratio for the number of personnel one SaS person and one BASOPS person can support on an installation. This approach assumes a new mission on an installation functions properly using the gaining installation's ratios.

INSTALLATIONS		MISSIONS			
NAME	CODE	ADMIN	RAD	TE	MAINT
Anniston	ANAD	1	0	0	1
Blue Grass	BGDA	1	0	0	1
Letterkenny	LEAD	1	0	0	1
Red River	RRAD	1	1	0	1
Sacramento	SAAD	1	0	0	1
Savanna	SVAD	1	1	0	0
Senacca	SEAD	1	1	0	1
Sierra	SIAD	1	0	0	0
Tobyhanna	TOAD	1	1	0	1
Tooele	TEAD	1	0	0	1
Aberdeen	APG	1	1	1	0
Charles Melvin Price	CMPS	1	0	0	0
Detroit Arsenal	DTA	0	1	0	0
Dugway Proving	DPG	1	0	1	0
Ft Monmouth	FTM	1	1	0	1
Harry Diamond Lab	HDL	1	1	0	0
Natick Research	NLS	1	1	0	0
Picatinny Arsenal	PTA	1	1	0	0
Redstone Arsenal	RSA	1	1	1	1
Rock Island Arsenal	RIA	1	1	0	0
Vint Hill Farms	VHFS	1	0	0	1
White Sands	WSMR	1	0	1	0
Yuma Proving Grnds	YPG	1	0	1	0
Hawthorne	HWAA	1	0	0	0
Holston	HLAA	1	0	0	0
Iowa	IAAP	1	0	0	0
Lake CIty	LCAA	1	0	0	0
Lone Star	LSAA	1	0	0	0
McAlester	MCAA	1	0	0	0
Milan	MAAP	1	0	0	0
Radford	RAAP	1	0	0	0
		ADMIN	RAD	TE	MAINT

Figure 15. Functions located at an Installation are depicted with a 1. For example, the model considers Administrative and Maintenance functions at Anniston.

INSTALLATION	CODE	SUPPORT	BASOPS
Anniston	ANAD	23.885	9.34
Blue Grass	BGDA	11.552	2.725
Letterkenny	LEAD	15.339	9.473
Red River	RRAD	11.76	10.407
Sacramento	SAAD	16.032	14.847
Savanna	SVAD	49.75	1.826
Senacca	SEAD	13.754	2.292
Sierra	SIAD	13.462	2.386
Tobyhanna	TOAD	26.68	13.205
Tooele	TEAD	23.106	9.967
Aberdeen	APG	5.234	55.515
Charles Melvin Price	CMPS	3.437	1.833
Dugway Proving	DPG	9.5	3.68
Ft Monmouth	FTM	10.218	60.816
Natick Research	NLS	7.029	8.269
Picatinny Arsenal	PTA	12.154	6.030
Redstone Arsenal	RSA	12.438	8.370
Rock Island Arsenal	RIA	18.667	10.397
Vint Hill Farms	VHFS	15.241	6.225
White Sands	WSMR	7.349	3.178
Yuma Proving Grnds	YPG	10.391	3.550
Hawthorne	HWAA	6.364	--
Holston	HLAA	3.111	--
Lake City	LCAA	4.333	--
Lone Star	LSAA	5.889	17.667
McAlester	MCAA	12.079	4.847
Milan	MAAP	3.615	--
Radford	RAAP	4.25	9.714

Figure 16. Installation service and support (SUPPORT) and Base Operations (BASOPS) ratios are listed.

APPENDIX D

The model's user can run one iteration of the model or a number of iterations to provide a set of alternatives. For each iteration the model provides the following reports:

- realignments of functions,
- personnel moved for each function realignment,
- civilian personnel lost for each function realignment,
- years lost attributed to the civilian personnel lost for each function realignment,
- military housing short for family, and unaccompanied housing for each installation as a result of function realignments,
- new construction space and cost for each function realignment,
- civilian workforce short for each function at each installation as a result of each function realignment to that installation,
- new personnel level at each installation for each function, support personnel, and base operations personnel,
- hiring costs for each installation for each function, support mission, and base operations,
- water, sewer, and electric utility shortages for each installation as a result of all realignments,
- and travel costs for each realignment for housing assistance, househunting, personnel transport, and household good shipments.

For each possible move, the model determines: lost years, lost personnel, travel cost, personnel moved, household goods moved, personnel levels for all functions, total costs attributed to one person, support and base operations ratios, maximum buildable acres, leasecosts, and housing maintenance costs.

The following information is consolidated into one value and reported for each iteration of the model:

- personnel moved,
- personnel lost,
- total hire costs,
- total square feet in new construction,
- cost of new construction,
- total travel costs,
- leasing costs,
- total operating cost,
- total lost years,
- and the λ mix used for each alternative realignment.

The following report listing is a sample of the computer output for five model runs. Each report is augmented with an explanation in italics. All reports were generated for FT Monmouth (FTM), Redstone Arsenal (RSA), and Vint Hill Farm (VHFS) MAINTenance functions. Similiar reports are generated for the remaining installations and R&D, T&E, and administrative functions.

REPORT 1. *Reports MOVES from DIVisible functions, in this case from MAINTenance functions. FTM.RSA refers to the move of the MAINT function from FTM to RSA.*

INDEX 1 = MOVES_DIV INDEX 2 = MAINT					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
FTM.RSA	1.000	1.000	1.000	1.000	
VHFS.RSA	1.000	1.000	1.000	1.000	1.000

REPORT 2. *PERSonnel MOVED for each realignment.*

INDEX 1 = PERS_MOVED INDEX 2 = MAINT					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
FTM.RSA	1884.200	1884.200	1884.200	1884.200	
VHFS.RSA	325.700	325.700	325.700	325.700	325.700

REPORT 3. *PERSonnel LOST for each realignment.*

INDEX 1 = PERSLOSS INDEX 2 = MAINT					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
FTM.RSA	413.800	413.800	413.800	413.800	
VHFS.RSA	51.300	51.300	51.300	51.300	51.300

REPORT 4. *NEW PERsonnel LEVel for each installation, for each function, and each personnel type. The C=Civilian, OF=OFficers, and EN=ENlisted. For example, the new Civilian personnel (C) at FTM for RUN-5 is 2157.*

INDEX 1 = NEW_PER_LEV INDEX 2 = MAINT					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
FTM.C					2157.000
FTM.OF					60.000
FTM.EN					81.000
RSA.C	3242.900	3242.900	3242.900	3242.900	1499.700
RSA.OF	75.000	75.000	75.000	75.000	15.000
RSA.EN	202.000	202.000	202.000	202.000	121.000
VHFS.C					
VHFS.OF					
VHFS.EN					

REPORT 5. *NEW PERsonnel LEVel for Base Operations at an installation.*

INDEX 1 = NEW_PER_SPT INDEX 2 = BO					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
FTM.C	16.624	16.624	16.624	16.624	88.579
RSA.C	709.424	691.934	691.934	883.089	987.364
VHFS.C	51.724	52.724	52.724	52.724	51.724

REPORT 6. *NEW PERsonnel LEVel for Service and Support at an installation.*

INDEX 1 = NEW_PER_SPT INDEX 2 = SAS					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
FTM.C	98.945	98.945	98.945	98.945	527.220
RSA.C	477.392	465.622	465.622	594.255	664.425
VHFS.C	21.127	21.127	21.127	21.127	21.127

REPORT 7. *Experience YEARS LOST due to a realignment (in man-years).*

INDEX 1 = YEARS_LOST INDEX 2 = MAINT					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
FTM.RSA	3897.900	3897.900	3897.900	3897.900	
VHFS.RSA	504.800	504.800	504.800	504.800	504.800

REPORT 8. *NEW CONSTRuction required at an installation for functions in thousands of square feet. For example, there is a requirment for 337000 SF of MAINT space at RSA for RUN-1.*

INDEX 1 = NEW_CONSTR					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
RSA.ADMIN					
RSA.MAINT	337.000	337.000	337.000	337.000	44.000

REPORT 9. *CONSTruction COST for functions at an installation in thousands of dollars.*

INDEX 1 = CONST_COST					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
RSA.ADMIN					
RSA.MAINT	44.484	44.484	44.484	44.484	5.808

REPORT 10. *WORK Force SHORT is the number of personnel that have to be replaced for each function. For example, 465 personnel have to be replaced at RSA for MAINT due to realignment losses.*

INDEX 1 = WORK_F_SHORT					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
RSA.MAINT	464.100	464.100	465.100	465.100	51.300
RSA.TE	124.900	77.300	77.300	77.300	77.300
RSA.BO					88.364
RSA.SAS					55.425

REPORT 11. *NEW CONSTRuction required for utilities for each installation in units outlined in Appendix A (WSC=Collection, WSD=Distribution, WST=Treatment, WSP=Disposal,). For example, FTM requires 212302 LF of water/sewar collection capability due to realignments in RUN-1.*

INDEX 1 = NEW_CONSTR					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
FTM.WSC	212.302	212.302	202.302	212.302	56.262
FTM.WSD	259.031	259.031	259.031	259.031	49.353
FTM.WST	2578.040	2578.040	2578.040	2578.040	1651.560
FTM.WSP	5367.640	5367.640	5367.640	5367.640	4002.300
FTM.ELPS	15713.200	15713.200	15713.200	15713.200	8886.480
FTM.ELPT	400.518	400.518	400.518	400.518	

REPORT 12. *CONSTruction COST for utilities at an installation in thousands of dollars.*

INDEX 1 = CONST_COST					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
FTM.WSC	15.923	15.923	15.923	15.923	4.200
FTM.WSD	19.427	19.427	19.427	19.427	3.701
FTM.WST	257.804	257.804	257.804	257.804	165.156
FTM.WSP	536.764	536.764	536.764	536.764	400.230
FTM.ELPS	1178.490	1178.490	1178.490	1178.490	666.486
FTM.ELPT	30.039	30.039	30.039	30.039	

REPORT 13. *Military HOUSing SHORT for each military type for each installation (UO=unaccompanied officers). For example, RSA is short 5 UO units for RUN-1.*

INDEX 1 = HOUSE_SHORT					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
RSA.UO	5.120			29.960	69.060
RIA.UO					
VHFS.UO					

REPORT 14. *HIRE COST for Base Operations personnel at each installation in thousands of dollars.*

INDEX 1 = HIRE_COST_BO INDEX 2 = BO					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
RSA.C					411.820

REPORT 15. *HIRE COSt for Service And Support personnel at each installation in thousands of dollars.*

INDEX 1 = HIRE_COS_SAS INDEX 2 = SAS					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
RSA.C					277.125

REPORT 16. *HIRE COST for function personnel at each installation in thousands of dollars.*

INDEX 1 = HIRE_COST INDEX 2 = MAINT					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
RSA.C	2325.500	2325.500	2325.500	2325.500	256.500

REPORT 17. *House HUNTing TRIP transportation costs in thousands of dollars. For example, the house hunting costs for FTM to RSA are $1,934,237.*

INDEX 1 = MAINT INDEX 2 = H_HUNT_TRIP					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
FTM.RSA	1934.237	1934.237	1934.237	1934.237	
VHFS.RSA	210.411	210.411	210.411	210.411	210.411

REPORT 19. *TRAVEL costs due to Personnel travel costs in thousands of dollars.*

INDEX 1 = MAINT INDEX 2 = TRAVEL_1					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
FTM.RSA	6390.001	6390.001	6390.001	6390.001	
VHFS.RSA	1071.599	1071.599	1071.599	1071.599	1071.599

REPORT 20. *TRAVEL costs due to house-hold goods shipped in thousands of dollars.*

INDEX 1 = MAINT INDEX 2 = TRAVEL_2					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
FTM.RSA	8121.426	8121.426	8121.426	8121.426	
VHFS.RSA	1220.491	1220.491	1220.491	1220.491	1220.491

REPORT 21. *Travel costs for HOUSing ASSISTance payments in thousands of dollars.*

INDEX 1 = MAINT INDEX 2 = HOUS_ASSIST					
	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
FTM.RSA	17549.143	17549.143	17549.143	17549.143	
VHFS.RSA	1816.461	1816.461	1816.461	1816.461	1816.461

REPORT 22. *This report has information for each possible realignment. For example, if FTM's ADMIN mission moved there would be 470 Civilian personnel lost, 4349 experience years lost, 1744 personnel moved, and the total house hold goods that would be moved is 5971 tons.*

	SPACE	LOS_C_PER	LOS_C_YEAR	PERS_MOVE	TOT-HHG
FTM.ADMIN		470.800	4349.900	1744.200	5971.200
FTM.MAINT		413.800	3897.900	1884.200	6473.200
FTM.RAD		457.600	4987.200	1620.400	5446.400
RSA.ADMIN		621.900	5581.600	2135.100	7405.350
RSA.MAINT		287.400	2559.100	1022.600	3564.100
RSA.TE		31.100	342.800	132.900	465.150
RSA.RAD		380.100	4180.300	1219.900	4256.150
VHFS.ADMIN		25.700	255.000	159.300	503.550
VHFS.MAINT		51.300	504.800	325.700	973.450

SPACE: leased space
LOS_C_PER: LOSt Civilian PERsonnel
LOS_C_YEAR: LOSt Civilian experience YEARs
PERS_MOVE: number of PERSonnel MOVEd
TOT_HHG: TOTal House Hold-Goods shipped
LEASE_COST: LEASing COSTs on an installation (not shown)

REPORT 22. *continued. For example, for FTM there are 7602 total personnel, 744 are SaS, 125 are BASOPS, SaS ratio is 10.2, BASOPS ratio is 60.8, total variable cost for a civilian is $36,378, total cost for enlisted and officers is $738, the maximum buildable space is 135,315 sf, and the cost to maintain military housing is $782,980.*

	FTM	RSA	VHFS
TOT_PERS	7602.000	7575.00	884.000
SPT_AT_F	744.000	609.000	58.000
BO_AT_F	125.000	905.000	142.000
SPT_SAS	10.218	12.438	15.421
SPT_BO	60.816	8.370	6.225
T_COSTS_C	36.378	30.949	36.106
T_COSTS_OE	0.738	0.849	0.606
MAXA	135315.000	1.288111E+7	659115.000
AFHCOSTS	782.980	6385.463	1703.449

TOT_PERS: TOTal PERSonnel
SPT_AT_F: SuPporT personnel AT installation F
BO_AT_F: Base Operations personnel AT installation F
SPT_SAS: SuPporT ratio for Service And Support
SPT_BO: SuPporT ratio for Base Operations
T_COSTS_C: Total COSTS for a Civilian
T_COSTS_OE: Total COSTS for military
MAXA: MAXimum buildable space
AFHCOST: Army Family Housing COST

REPORT 23. *TRAVEL cost to move from installation f to f' in thosands of dollars. For example, it would cost $18,897,000 to move RSA's MAINT function to SAAD.*

INDEX 1 = TRAVEL_TO			
	MAINT.FTM	MAINT.RSA	MAINT.VHFS
RRAD			
SAAD		1[illegible]63	4596.625
SVAD			
SEAD			
SIAD	33994.807		4318.961
TOAD			
TEAD			

REPORT 24. *Consolidated report in thousands of dollars.*

	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
MAXH	47919.700	47720.700	46435.200	36697.900	20833.600
T_HIRECOST	47919.700	47720.734	46435.224	36697.924	20833.633
J_HIRECOST	34778.500	34515.500	33578.500	25923.000	13552.500
S_HIRECOST	13141.200	13205.234	12856.724	10774.924	7281.113
PERS_MOVED	27337.300	27175.900	26501.112	20653.400	11371.500
PERS_LOS_J	6955.700	6903.100	6715.696	5184.600	2710.500
PERS_NEW_S	2628.240	2641.047	2571.047	2154.985	1456.227

REPORT 24. (continued)

	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
MAXC	307353.000	311593.000	307317.000	294138.000	211276.000
MAXC_NO_WV	261460.424	265713.832	261485.485	248855.066	167397.034
CON_J_COST	261459.528	265714.099	261485.548	248855.723	167397.274
CON_W_COST	20969.540	20965.444	20933.973	20753.497	20135.668
CON_V_COST	24923.036	24913.724	24897.542	24529.437	23743.299
T_J_NEWCON	1770568.650	1805057.650	1778499.740	1702943.050	1169008.670
T_V_NEWCON	339529.980	339421.523	339210.249	333840.144	324446.192
T_W_NEWCON	214785.539	214748.403	214432.763	212329.786	206151.938

	TOT_TRAVEL	MAXT
RUN-1	493506.801	493507.000
RUN-2	490925.578	490926.000
RUN-3	478709.752	478710.000
RUN-4	371839.609	371840.000
RUN-5	207898.741	207899.000

REPORT 24. (continued)

	RUN-1	RUN-2	RUN-3	RUN-4	RUN-5
NEW_Z1_CST	1453923.333	1454181.674	1455688.166	1482028.215	1537285.018
Z2_YEARS	62162.400	61573.400	59487.000	45929.700	24280.700
Z3_COMBINE	1411690.000	1430890.000	1476730.000	1498010.000	1518010.000
LAMBDA	0.999	0.995	0.985	0.980	0.970

MAXH: MAXimum Hire cost (combination of T+J+S below)
T_HIRECOST:Total HIRE COST for realignment (should be same as MAXH)
J_HIRECOST:HIRE COST for functions
S_HIRECOST:HIRE COST for support and base operations
PERS_MOVED:Total PERSonnel MOVED
PERS_LOS_J:Total PERSsonnel LOSt for functions
PERS_NEW_S:NEW level of support PERSonnel
MAXC:MAXimum Construction cost (combination of J+W+V below)
MAXC_NO_WV:MAXimum Construction cost without utilities
CON_J_COST:MAXimum Construction cost for functions
CON_W_COST:MAXimum Construction cost for water/sewer
CON_V_COST:MAXimum Construction cost for electric
T_J_NEWCON:Total NEW CONSTRUCTION in square feet for functions
T_V_NEWCON:Total NEW CONSTRUCTION in appropriate measure for electric
T_W_NEWCON:Total NEW CONSTRUCTION in appropriate measure for water/sewer
TOT_TRAVEL:TOTal TRAVEL costs
MAXT:MAXimum Travel costs (should be same as TOT_TRAVEL)
NEW_Z1_CST:Total operating cost
Z2_YEARS:Total lost years
Z3_COMBINE:a linear combination of the two objective functions
LAMBDA:weighting for operating cost objective (lost years weighting is 1-LAMBDA)

LIST OF REFERENCES

1. Department of the Army, Office of the Assistant Secretary of the Army for Installations, Logistics, and Environment, *Questions and answers raised about the Army Materiel Command's Vision 2000,* 01 May 1991.

2. Army Materiel Command, The Office of the Deputy Chief of Staff for Management, *Zero-Based Resourcing Implementation Guide*, Second Edition, 22 April 1991.

3. Department of the Army, Office of the Assistant Secretary of the Army for Installations, Logistics, and Environment, *Recorded Version of Statements Regarding Base Realignment and Closures*, 26 April 1991.

4. Department of the Army, *Base Closure And Realignment Recommendations: Detailed Analysis*, April 1991.

5. Public Law 101-510, Title 19, US Code.

6. Logistic Management Institute, *COBRA: The Base Closure Model*, May 1989.

7. Army Materiel Command, *AMC's Vision 2000, Economic Analysis, Methodology/Assumptions*, 4 March 1991.

8. Army Materiel Command, The Office of the Deputy Chief of Staff for Management, *Q&As on Vision 2000 for Congressional Hearings*, Undated.

9. Department of Defense, *Base Closure and Realignment Report*, April 1991.

10. The U.S. Army Audit Agency, *Lessons Learned For Future Basing Studies*, 17 September 1991.

11. Department of the Army, Office of The Chief of Engineers, *U.S. Army Corps of Engineers Reorganization Study*, 22 February 1991.

12. Dell, R., Parry, S., Rosenthal, R., *Modeling Army Maneuver and Training Base Realignment and Closure: A Mixed Integer Programming Approach,* Naval Postgraduate School, May 1992.

13. Singleton, J. G., *Stationing United States Army Units To Bases: A Bi-Criteria Mixed Integer Programming Approach*, Naval Postgraduate School, June 1991.

14. Francis R., McGinnis L., White J., "Location Analysis", *European Journal of Operations Research*, 12, 1983, 220-252.

15. Current J., Min H., Schilling D., "Multiobjective Analysis of Facility Location Decisions", *European Journal of Operations Research*, 49, 1990, 295-307.

16. Brown, G. G., and Graves, G. W., *Elastic Programming: A New Approach to Large-Scale Mixed Integer Optimization*, ORSA/TIMS Joint National Meeting, Las Vegas, Nevada, 1975.

17. U.S. Army Materiel Command Management Branch provided a listing of Standard Factors used in the BRAC process. Similar factors are contained in Reference 10.

18. Brooke, A., Kendrick, D., Meeraus, A., *GAMS: A User's Guide*, The Scientific Press, 1988.

19. Byer, J., XA, *Professional Linear Programming System*, Sunset Software Technology, 1987-1992.

20. Cohon, Jared L., *Multiobjective Programming and Planning*, Academic Press, New York, 1978.

21. Richardson and Kirmse, Incorporated, *Real Property Planning and Analysis System (RPLANS)*, October 1990.

22. U. S. Army Materiel Command Management Engineering Activity, provided data for functions, personnel, and grade distribution for each installation.

23. Department of Defense, *Joint Travel Regulation U8000*, Chapter 8, 1992.

24. AR 55-60/NAVSO P2471/AFR 117-135 Department of the Army, Navy, and Air Force, *Official Table of Distances, CONUS, Alaska, Hawaii, Canada, Canal Zone, Central America, Mexico, and Puerto Rico*, 1 December 1981.

25. Military Traffic Management Command, *Traffic Management Progress Report*, 4th QTR FY 1990, 25 April 1991.

26. R. S. Means Co., *Means Site Work Cost Data*, Vol 89, 8th edition, 1989.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, VA 22304-6145	2
2.	Library, Code 52 Naval Postgraduate School Monterey, CA 93943-5002	2
3.	Professor Robert Dell, OR/De Department of Operations Research Naval Postgraduate School Monterey, CA 93943	2
4.	Professor Samuel H. Parry, OR/Py Department of Operations Research Naval Postgraduate School Monterey, CA 93943	1
5.	Professor Richard E. Rosenthal, OR/Rl Department of Operations Research Naval Postgraduate School Monterey, CA 93943	1
6.	Department of the Army The Pentagon, Room ME670 ATTN: DISA/DSSO/JNSV (ATTN: CPT William J. Tarantino) Washington, DC 20310-0412	2
7.	Department of the Army The Pentagon, Room 30255 ATTN: OCSA, DACS-DM(TABS) (CPT Charles Fletcher) Washington, DC 20310-0412	1
8.	U. S. Army Materiel Command ATTN: AMC-SX (Ed Curle) 5001 Eisenhower Ave Alexandria, VA 22333	2