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Optimal Stationing of US Army Forces in Korea

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

OPTIMAL STATIONING OF US ARMY FORCES IN KOREA

by

Muzaffer Gezer

December 2001

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Closing and realigning installations has long been a part of the United States (US) Army's reformation. Since 1988, more than 100 Army bases have been closed and 20 others significantly realigned within the US. Since the end of the Cold War, the US Army has closed seven of every ten bases in Europe. These extensive overseas closures do not receive the same level of US public attention as those taking place within the US but they represent the fundamental shift from a forward-deployed force to one relying upon overseas presence and power projection. To develop closure and realignment recommendations for installations located in the US, the Army has developed the integer linear program OSAF (Optimal Stationing of Army Forces). This thesis modifies OSAF to study the stationing of US units and closure of US installations in South Korea. We call the modified model OSAFK (Optimal stationing of US Army Forces in Korea). OSAFK examines multiple stationing alternatives simultaneously and provides an optimal (minimum cost) stationing for a given set of units and installations while observing budgetary restrictions and stationing policy. We demonstrate OSAFK using a limited data set that considers 51 installations and 194 units. We compare the 20-year net present value of the total cost and the stationing recommended by OSAFK under various levels of budget and find the potential for a substantial reduction to the 20-year net present value.

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OPTIMAL STATIONING OF THE US ARMY FORCES IN KOREA

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Closing and realigning installations has long been a part of the United States (US) Army's reformation. Since 1988, more than 100 Army bases have been closed and 20 others significantly realigned within the US. Since the end of the Cold War, the US Army has closed seven of every ten bases in Europe. These extensive overseas closures do not receive the same level of US public attention as those taking place within the US but they represent the fundamental shift from a forward-deployed force to one relying upon overseas presence and power projection. To develop closure and realignment recommendations for installations located in the US, the Army has developed the integer linear program OSAF (Optimal Stationing of Army Forces). This thesis modifies OSAF to study the stationing of US units and closure of US installations in South Korea. We call the modified model OSAFK (Optimal stationing of US Army Forces in Korea). OSAFK examines multiple stationing alternatives simultaneously and provides an optimal (minimum cost) stationing for a given set of units and installations while observing budgetary restrictions and stationing policy. We demonstrate OSAFK using a limited data set that considers 51 installations and 194 units. We compare the 20-year net present value of the total cost and the stationing recommended by OSAFK under various levels of budget and find the potential for a substantial reduction to the 20-year net present value.

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LIST OF ACRONYMS

BOS	Base Operation Support
CPX	Complex
DIST	District
FCG	Facility Category Group
GAMS	General Algebraic Modeling System
ISR	Installation Status Report
MILCON	Military Construction
NPV	Net Present Value
OSAF	Optimal Stationing of Army Forces
OSAFK	Optimal Stationing of US Army Forces in Korea
RPM	Real Property Maintenance
RS	Residence
SF	Square Feet
US	United States
USKF	United States Force Korea

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EXECUTIVE SUMMARY

Since 1988, more than 100 Army bases have been closed and 20 others significantly realigned within the United States (US). Since the end of the Cold War, the US Army has closed seven of every ten bases in Europe. These extensive overseas closures do not receive the same level of US public attention as those taking place within the US but they represent the fundamental shift from a forward-deployed force to one relying upon overseas presence and power projection. To develop closure and realignment recommendations for installations located in the US, the Army has developed the integer linear program OSAF (Optimal Stationing of Army Forces). This thesis modifies OSAF to study the stationing of US units and closure of US installations in South Korea. We call the modified model OSAFK (Optimal stationing of US Army Forces in Korea). OSAFK examines multiple stationing alternatives simultaneously and provides an optimal (minimum cost) stationing for a given set of units and installations while observing budgetary restrictions and stationing policies.

OSAFK introduces a four-area breakdown to mirror the existing support and mission area breakdown for US Army units in South Korea; OSAFK restricts a unit to be stationed only to one of a set of installations located within the area where the unit is currently located. OSAFK also introduces the idea of dependent installations that must be closed when their supporting installation closes.

Using the limited data set available for our study, we find a significant shortage between infrastructure required by US Army units currently stationed in South Korea and available infrastructure. Our results indicate it would require just under $5.5 billion to provide adequate facilities for US Army units for just the 27 facility category groups we consider. With just a small increase above this $5.5 billion, OSAFK recommends a large number of installation closures. Under our assumed cost structure, this recommendation suggests the benefit (over $11 billion reduction to the 20-year net present value cost) of an extensive MILCON program on a comparatively smaller number of installations.

After enhancing OSAFK with more realistic training and cost data, we recommend the US Army use OSAFK to help guide the closure and realignment of its installations in South Korea.

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I. INTRODUCTION

A recent joint United States Force Korea (USFK), and Republic of Korea initiative is the Land Partnership Plan. Without any force reduction, the Land Partnership Plan calls for USFK to consolidate the current small, isolated installations on the South Korean peninsula into larger, more enduring installations. The Land Partnership Plan consolidation promises higher force protection, better use of training areas for all units, improved working and living conditions, and cost savings. [Woodgerd 2001]

United States (US) Army installations in South Korea have unique characteristics that differentiate them from their counterparts located within the US. They are dispersed on the peninsula on a mission-oriented basis and any consolidation of these installations must preserve the best formation for their mission.

To help develop closure and realignment recommendations for installations in the US, the Army has developed the integer linear program OSAF (Optimal Stationing of Army Forces) [Tarantino 2001]. This thesis modifies OSAF to study the stationing of units and closure of US Army installations in South Korea. The modified integer linear program is called Optimal Stationing of US Army Forces in Korea (OSAFK). OSAFK examines multiple stationing alternatives simultaneously and provides an optimal (minimum cost) stationing for a given set of units and installations while observing budgetary restrictions and stationing policies.

In the following sections, we provide some background on US Forces in Korea and introduce OSAFK inputs.

A. US FORCES IN SOUTH KOREA

Located in the eastern Asia, the Korean Peninsula consists of 220,847 square kilometers with one nation, Korea, and two countries, North and South Korea. The total population on the peninsula adds up to 70 million people.

The US has a significant army presence in South Korea. It follows as a direct result of US involvement in the Korean Theatre to halt communist expansion following World War II. On 25 June 1950, the Korean War broke when North Korea launched an unprovoked attack across the 38^{th} parallel. The three-year war with a total of almost 28,000 US casualties, 77,000 US wounded, and 3,700 US missing in action, ended in an armistice agreement.

Korea is different from other areas and regions around the world. The current state is armistice but not peace. The armistice does not mean that the war is over; it is a suspension of hostilities – an interruption of the shooting. The war itself has never officially ended. [Schwartz 2001]

North Korea is the fifth largest military with a nuclear capability. The number of artillery exceeds 12,000, tanks 4,000, aircraft 1,700 and ships 800. In a period of time when many nations are downsizing, North Korea continues to add quantity, and since 1980, they have forward deployed 70% of their combat power to the front lines. It is obvious that they are trying to build an intercontinental missile. North Korea also appears to have the potential capability to produce chemical and biological agents. Still, beyond its capabilities, North Korea has proven it intends to avoid any sincere steps for resolution and peace. For North Korea, the survival of the regime comes above all else, even at the expense of millions of starving North Koreans. [Schwartz 2001]

Currently the US Army has a force deployment of 37,000 soldiers in South Korea, with plans to increase this up to 600,000 in case of war. The mission of USFK can be summed up as "to remain vigilant and focused on the readiness," "actively support reconciliation" and "to promote regional stability with forces that have an acceptable quality of life" [Schwartz 2001].

Peak USFK personnel turnover takes place in June and July, and the exercise program goes on the whole year. US Army personnel serving time on the peninsula usually experience a one-year separation from their family and substandard facilities, as well as extra training and work. There is a significant shortage in all areas of infrastructure, unaccompanied housing, family housing, war fighting projects, and support facilities. The USFK facility deficiencies are estimated to be $7 billion. [Schwartz 2001]

The ideal situation for US Forces in Korea is *Balanced Readiness*, the saddle point between training, readiness and quality of life. USFK command has a vision to end one-year-at-a-time rotations and enhance force protection, sustain training, improve quality of life, and increase on-post family housing. Schwartz [2001] reports, without listing specific closures, that these changes will include the closure of fifteen installations out of a subset of 41 on the peninsula and a ten-year program for funding Military

Construction (MILCON). These changes are essential to restore the installations to standards approaching those in the US. [Schwartz 2001]

B. CURRENT ARMY UNITS AND INSTALLATIONS IN SOUTH KOREA

1. US Army Installations in South Korea

US Army installations in South Korea can be grouped into two categories. In this thesis, we primarily concern ourselves with the first category of installation where the majority of units are stationed. The second category consists of separate ranges and training areas. Table 1 lists the 51 US Army installations in South Korea that we consider in this thesis. (The Appendix contains a map of South Korea that shows the location of these installations.) The Eighth United States Army stationed at these installations is mainly divided in four support and operation regions on the peninsula. Each of these installations belongs to a support region [US Department of the Army 2001a]. This area breakdown not only facilitates the support and supply of installations but defines the mission formation of units as well. Figure 1 shows the map of the first category of installations located in Area I.

Area I Installations		Area II Installations		Area IV Installations	
Code	**Name**	**Code**	**Name**	**Code**	**Name**
KS021	GARY OWENS	KS134	COLBERN	KS054	CARROLL
KS041	CASEY	KS399	MARKET	KS196	HENRY
KS064	CASTLE	KS670	YONGSAN	KS199	HIALEAH
KS149	GREAVES	KS709	K16 AIRFIELD	KS585	PUSAN STORAGE
KS150	ESSAYONS	KS970	YONGIN	KSA24	PIER 8
KS155	EDWARDS	KSA27	RETREAT CENTER	KSA43	TAEJU RS
KS157	FALLING WATER	KSA42	SUNGNAM	KSA48	PUSAN RS
KS180	GIANTS	KSA47	AREA II RS		
KS194	HOVEY	KS816	TANGO		
KS197	HOWZE	KS461	NOBLE		
KS218	CHUNCHON	KS165	GRAY		
KS275	JACKSON	KS145	ENGINEERING DIST.		
KS375	KYLE KS				
KS378	LAGUARDIA	**Area III Installations**			
KS462	NIMBLE	**Code**	**Name**		
KS472	BONIFAS	KS151	EAGLE		
KS533	PAGE	KS208	HUMPHREYS		
KS599	RED CLOUD	KS390	LONG		
KS658	SEARS	KSA49	PYONGTAEK		
KS712	STANLEY	KSA21	PYONGTEAK CPX		
KS715	STANTON	KS045	WONJU RS		
KS996	H220				
KSA08	SWISS SWED				
KSA44	UIJONGBU			DIST	District
KSA45	MUNSAN RS			RS	Residence
KSA46	TONGDUC RS			CPX	Complex

Table 1. List of Installations by Area. The Appendix contains a map of South Korea that shows the location of these installations.

Due to limited data availability, this thesis does not consider training ranges contained in the second category of installations. For purposes of our analysis, this is equivalent to assuming that (1) after restationing, these training areas and ranges are still available for unit training and (2) restationing does not alter the cost to train at these installations.

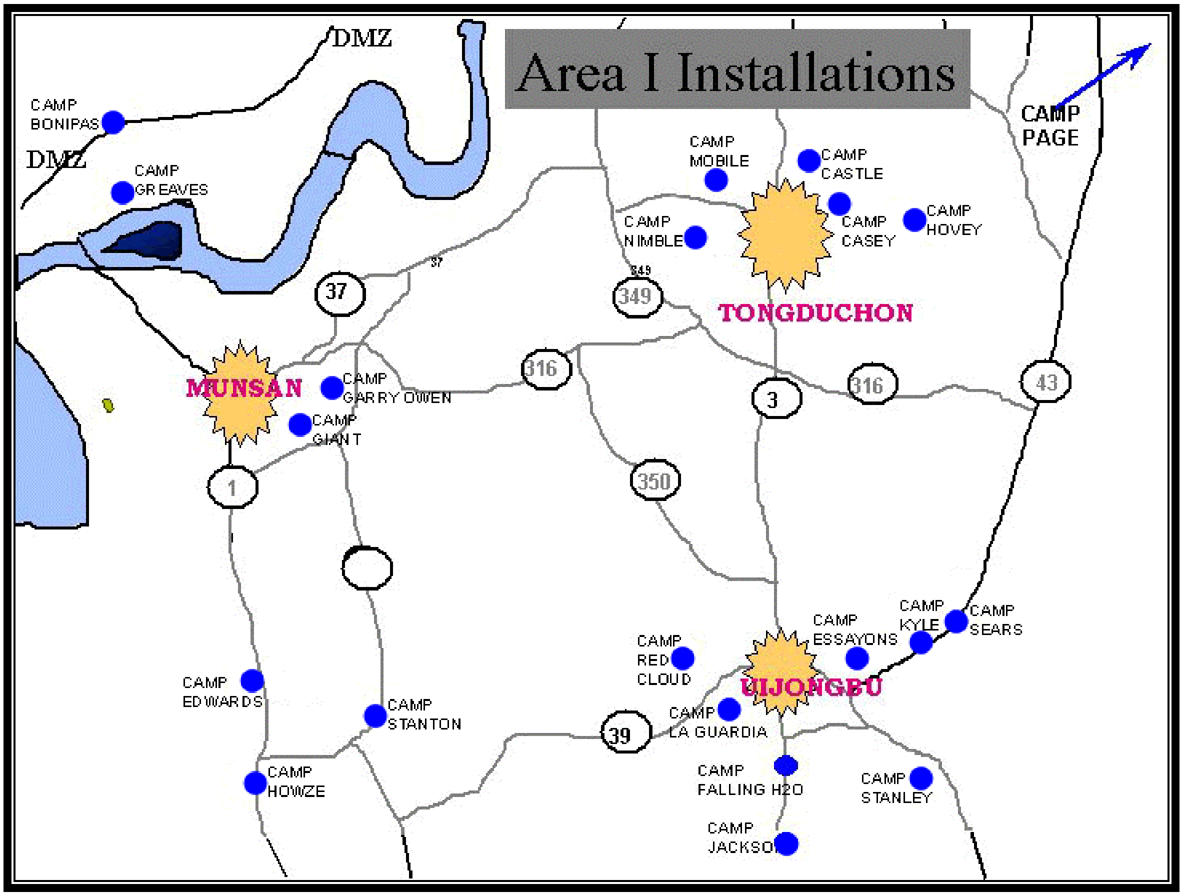

Figure 1. Map of Area I Installations. Installations located in Area I are primarily concentrated in three different locations. [Figure after US Department of the Army 2001b]

Some of the installations we consider rely on the existence of a larger installation located nearby to supply services to stationed units. For example, Camp Castle is within walking distance of Camp Casey, and Camp Casey offers many of the services not available on Camp Castle [US Department of the Army 2001c]. For purposes of this thesis we model this relationship by assuming all dependent installations close when the supporting installation closes but not vice-versa. For example, OSAFK may recommend closing Camp Castle and leaving Camp Casey open but Camp Castle must close if Camp Casey closes. This extension was not previously considered in OSAF. Dependencies can also be extended to training assets needed by a dependent installation. For example, the Bonifas Combat Pistol Qualification Course (KS540) depends on Camp Bonifas (KS472).

2. Facility Category Groups

The US Army divides its infrastructure into 353 Facility Category Groups (FCGs). Based primarily on OSAF analysis [Tarantino and Connors 2001] as well as our analysis of data on unit demand and installation availability, OSAFK uses eight range FCGs (Table 2) and 27 facility FCGs aggregated into 13 different categories (Table 3). These FCGs encompass more than 36% of the facility square feet represented by all FCGs measured in square feet in South Korea. Tarantino and Connors [2001] find the remaining 64% are not significant factors for prior stationing studies.

FCG	**FCG Description**
F17804	RECORD FIRE RGS
F17801	ZERO RANGES
F17831	MACHINE GUN QUAL
F17852	MORTAR RANGES
F17864	MULTIPURPOSE TNG RG
F17866	MPRC
F17894	INF BATTLE CSE
F17802	FIELD FIRE RGS

Table 2. Range FCGs

FCG Group	FCG	FCG Description
1	OPERATIONS / ADMINISTRATIVE	
	F14182	HQ BLDG, BDE
	F14183	HQ BLDG, BN
	F14185	HQ BLDG, CO
	F60000	ADMIN FACS
	F13115	INFO SYS FACS
2	AVIATION MAINTENANCE	
	F21110	ACFT MAINT FACS
3	VEHICLE / DOL MAINTENANCE	
	F21410	VEH MAINT SHOPS
	F21885	VEH MNT DOL/DEH
4	SUPPLY / STORAGE	
	F44210	ENCL STOR INST
	F44224	UNIT STOR BLDGS
5	TRAINING / INSTRUCTION (ACTIVE)	
	F17120	GEN INST BLDGS
	F17138	LIMIT USE INST
	F17119	ORG CLA SSROOM
6	COMMUNITY FACILITIES	
	F74014	CHILD DEV CTRS
	F74028	FITNESS FACS
	F74053	EXCH RETAIL FAC
	F72200	UPH DINING FACS
	F74046	OPEN DINING
	F74021	COMMISSARIES
7	FAMILY HOUSING	
	F7110F	FAM HSG FAMS
8	ENLISTED UPH	
	F7210P	UPH, ENL SPACES
	F7213P	UPH, ENL STU SP
9	OFFICER UPH	
	F7240P	UPH OFFICER SP
10	NCO UPH	
	F7217P	UPH SR NCO SP
11	AT/MOB SPACES	
	F7211P	AT/MOB SPACES
12	AMMUNITION STORAGE	
	F42200	INST AMMO STOR
13	BULK FUEL STORAGE	
	F41100	BULK FUEL STOR

Table 3. Facility FCGs

All facilities are categorized into permanent assets, semi-permanent assets, and temporary assets. Depending on their condition, permanent and semi-permanent assets are also categorized into the Installation Status Report (ISR) [US Department of the Army 2000] rating for the quality of an installation facility type as green for good, yellow for fair, or red for poor.

For computational convenience and to accommodate available data, this thesis combines temporary assets and semi-permanent assets and treats them as other-rated facilities, while permanent assets are treated as green-rated. These green-rated facilities account for only six percent of the total FCG assets considered in this thesis.

3. Units and Unit Requirements

Tarantino [2001] provides data for 194 USFK units with each unit categorized into one of ten different types (Table 4).

	Unit Types
1.	2^{nd} Infantry Division
2.	Combat Support
3.	Special Activity
4.	Garrison
5.	Tenants
6.	Support Forces
7.	Non Divisional Combat
8.	25^{th} Infantry Divisions
9.	US Army Reserve Full Time Service
10.	Training Forces

Table 4. Unit Types

For purposes of some cost and requirements, personnel comprising these units are categorized into two overall groups: civilians and military. Civilians are further categorized into two groups: "US civilians" and "other civilians." Like civilians, military also grouped into two subsets: "enlisted" and "officer" which also includes noncommissioned officers.

Because unit readiness is vital, adequate training lands and ranges must be provided at or in close proximity to the location where a unit is stationed. OSAFK assumes either (1) units can train at any installation within their support area or (2) a unit can use only the training assets at the installation where they are stationed.

Facilities are essential to support to USFK's mission as well as to provide "quality of life" for stationed soldiers. Quality of life along with training and readiness are the key elements for a Balanced Readiness [US Department of the Army 2001d]. OSAFK recommends a strategy for improving the existing housing facilities and adding new MILCON, a necessary step to make this objective viable.

4. Stationing Costs

Closing installations, moving units, and supplying sufficient infrastructure both for mission readiness and quality of life requires funding. As with OSAF, OSAFK seeks to minimize the 20-year net present value cost for stationing units while observing budget availability and a stationing policy.

The one-time (or upfront) cost is the cost of implementing a stationing plan. OSAFK one-time expenditures includes MILCON to accommodate moving units, funds to manage the movement of units to a different location, and to manage the closure of an installation that is no longer needed.

OSAFK can consider MILCON for married personnel and quarters for unmarried personnel in response to the quality of life initiative. There is a different housing allowance for each personnel type depending on whether they have families or not. Housing costs also vary among support areas I, II, III, and IV.

Recurring costs consists of Base Operation Support (BOS), real property maintenance (RPM), and housing operations and allowances. The BOS cost comprises the overhead cost (fixed cost) of having an installation open, regardless of how many units are stationed there, and the cost (variable cost) of stationing individual units at a particular installation.

C. THESIS OUTLINE

Chapter II provides a literature review. Chapter III presents the OSAFK model. Chapter IV reports computational results and chapter V contains conclusions.

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II. LITERATURE REVIEW

There have been a significant number of studies on base realignment and closure. This chapter reviews some recent optimization modeling to support US Army stationing.

The Center for Army Analysis developed OSAF for the Assistant Chief of Staff for Installation Management, Headquarters, Department of the Army [Tarantino and Connors 2001]. OSAF can systematically examine the optimal stationing of a US Army force structure (current or future) based on infrastructure requirements, training requirements, installation capabilities, costs, and stationing and budget restrictions [Connors, Dell, and Tarantino 2001]. OSAF serves as a basis for our development of OSAFK.

OSAF [Connors, Dell, and Tarantino 2001] views a force-structure stationing as a tradeoff amongst shortfalls in facility and range requirements, yearly recurring cost, and one-time restationing cost. By varying the allowed shortfall and one-time cost, OSAF provides alternatives for a given force structure. OSAF views infrastructure in aggregated facility and range groups and quantitatively measures any shortfall in facility or range requirements for stationing alternatives of various force structures. Because the yearly cost of maintaining facilities and ranges impacts the US Army's ability to maintain facilities for training, OSAF minimizes the yearly recurring cost to maintain infrastructure at all installations for a given measure of shortfall. Because there could be a large one-time restationing cost to move units to different installations in order to achieve the minimum yearly recurring cost, OSAF limits the maximum one-time cost. Because OSAFK extends OSAF, our approach preserves all these features.

Loerch et al [1996] present another integer linear program to assist with developing feasible stationing alternatives, evaluating the strengths and weaknesses of alternatives, and facilitating tradeoff analyses for US Army installations in Europe. They consider costs (both recurring and one-time expenditures), quality of life of both the soldiers and their families, and the accomplishment of mission requirements as driving factors for their study. The cost has two parts: one is the overhead cost of having the installation open, and the other is the cost of implementing any stationing plan that involves the one time expenditure for unit movement, closure of the installations that are no longer needed and the severance pay to local national employees of the US Army whose services are no longer required. The recurring unit stationing cost is based on factors such as the type of unit, the location of the installation, or the cost of living at that location. Quality of life issues center around over-crowding installations and ensuring that no unit can be assigned to a location unless an adequate amount of the appropriate resources are available to meet the unit's requirement. Regarding the mission requirements, units must be stationed close to their area of operation and places that facilitate their rapid movement.

As reported by Loerch et al, the total number of units in the reduced force structure of the US Army in Europe was about 1,200 and the number of individual installations used by the Army in Europe was about 350. Due to the size of the data, the authors use some aggregation of installations and units. Small units with small numbers of personnel and assets are not included in their study. Combat units, particularly infantry, armor, cavalry, and artillery companies are aggregated into battalions. Battalions, rather than companies, are assigned to installations. Some of installations are specifically designated for training purposes while others are designated for housing, administration, or support. None of these installations are sufficient by themselves to support the stationing of an aggregated unit, but together they supply adequate resources.

Like the model described by Loerch et al, OSAFK considers some grouping of installations. Specifically, OSAFK considers groups of installations within their support area as supplying aggregate resources for training. Unlike the model described by Loerch et al, OSAFK does not aggregate units and OSAFK also introduces the idea of dependent installations that must be closed when their supporting installation closes.

III. OSAFK

OSAFK is an integer linear program that enables a systematic examination of US Army stationing alternatives and prescribes an optimal US Army stationing for a given set of units and installations while observing budgetary restrictions and stationing policy. We discuss several key assumptions before presenting a formulation.

A. OSAFK ASSUMPTIONS AND RESTRICTIONS

Unless indicated otherwise, the assumptions listed below are consistent with those found in OSAF.

1. Installations

We require OSAFK to keep special installations open. For example, we may require Camp Yongsan and Camp Casey to remain open because they both have a medical center.

2. Units

We restrict unit stationing to be within their current support area and we assume garrison units do not move even if the installation is closed.

OSAFK assumes that any unit stationed to a new installation is assigned green-rated facilities or new construction. For this reason, OSAFK applies an upgrade cost when only other-rated facilities are available and unoccupied. OSAFK does not upgrade the facilities for units that remain on an installation (units that do not move) and assumes that green-rated facilities are the last ones to be evacuated by units leaving an installation.

3. Base Operation Support

Installations that are kept open generate a BOS cost. The fixed BOS cost depends on the location of the installation. The variable part is calculated from the number of personnel at a cost per person.

4. Real Property Management

There is a requirement to maintain facility conditions. This maintenance cost per square foot depends on the condition of the facility and location of the installation.

5. Housing and Quarters

We assume, for purposes of housing requirements, that 54% of the enlisted personnel are married and 71% of the officers are married.

6. Ranges and Maneuver Land

Ranges can be consolidated among various installations. Unlike OSAF, we assume that all ranges are consolidated within their support area and that any stationed unit can train at any of the ranges that are part of the consolidated asset. Thus, any installation can supply training opportunities for units within the same area.

Assuming US Army Forces in South Korea will either retain training land or maintain access to important assets after returning them to South Korea, US Army units will have the same amount of training land available. Therefore, OSAFK does not include training land requirements and capacities as found in OSAF.

7. Moving and Management Cost

OSAFK does not use a location-to-location unit movement cost as in OSAF. Instead we use OSAF's movement and closure program costs. For program management, it is assumed to cost $2.55 per square foot for mothball, $2.41 per square foot for transitioning to unoccupied, and $0.36 per square foot for caretaker [Tarantino and Connors 2001].

B. OSAFK FORMULATION

For consistency, OSAFK maintains most of the notation found in OSAF [Tarantino and Connors 2001].

1. Indices

c facility condition (green, other)

f facility category code (OPS_ADMIN, AVMAINT, VEH_DOL, SUP_STORE, ACTRNG, COMMFAC, AMMOSTORE, BULK_FUST, FH,EUPH, OUPH, NCOUPH, ATMOB_SP)

i installation codes

r range type (RECFIRE, ZERO, MGUN, MORTAR, MPTR, MPRC, INFBATCSE, FFRGS)

u unit

pt personnel types

2. Sets

CA_u set of installations where unit *u* can be assigned

IS_i initial stationing of units at installation *i*

MT set of installations where units must train where assigned

UA_i set of units that can be assigned to installation *i*

DPD_i set of installations that must close if installation *i* closes

N set of ranges requiring construction to satisfy any shortage

S1 set of installations where a subset of installations can train for Area I (assets are consolidated)

S2 set of installations where a subset of installations can train for Area II assets are consolidated)

S3 set of installations where a subset of installations can train for Area III (assets are consolidated)

S4 set of installations where a subset of installations can train for Area IV (assets are consolidated)

3. Data

All $ are fiscal year 2001 thousands of dollars and all SF are thousands of square feet.

a. Cost data

$Fcost_i$	fixed cost of keeping installation *i* open ($)
$MANcostM_u$	program management cost for moving unit *u* ($)
$MANcostC_i$	program management cost for closing installation *i* ($)
maxMILCON	maximum one-time cost for military construction ($)
maxMAN	maximum management cost ($)
maxCOST	maximum one-time (upfront) cost ($)
$MILCONcost_{fi}$	military construction (MILCON) cost for facility type *f* at installation *i* ($/SF)
$RNGcost_{ri}$	cost for a new range *r* at installation *i* ($/range)

$UPcost_{fi}$	cost to upgrade facilities type *f* at installation *i* ($/SF)
$Vcost_{iu}$	variable cost if unit *u* is assigned to installation *i* ($)
$CostSustain_{if}$	cost to sustain old facilities type *f* at installation *i* ($/SF)
$Cost\_New_{if}$	cost to sustain new facilities type *f* at installation *i* ($/SF)

b. Range data

$RANm_r$	maximum range days on a new range *r* (day)
$RANrcap_{ir}$	range capacity of type *r* at installation *i* (day)
$RANrreq_{ru}$	range required of type *r* for unit *u* (day)
$RANrshort_r$	existing range shortage for range type *r* (day) Calculated as:

$$RANrshort_r = \max\left\{0,\ \sum_i \left(\sum_{u \in IS_i} RANrreq_{ru} - RANrcap_{ir}\right)\right\}$$

$allowRNG\_S1_r$	the starting range shortage allowed for set *S1* (day)
$allowRNG\_S2_r$	the starting range shortage allowed for set *S2* (day)
$allowRNG\_S3_r$	the starting range shortage allowed for set *S3* (day)
$allowRNG\_S4_r$	the starting range shortage allowed for set *S4* (day)
$moreRNGshort_r$	fractional range *r* shortage to multiply to $RANrshort_r$ (day/day)
$ADDRNG\_S1_r$	shortage allowed for range *r* and set *S1* (day)
$ADDRNG\_S2_r$	shortage allowed for range *r* and set *S2* (day)
$ADDRNG\_S3_r$	shortage allowed for range *r* and set *S3* (day)
$ADDRNG\_S4_r$	shortage allowed for range *r* and set *S4* (day)
MinRANGshort	the minimum range shortage before a range purchased (day)

c. **Facility data**

$FACcap_{fic}$ — all facility capacity type *f* at installation *i* condition *c* (SF)

$FACreq_{fu}$ — facility required of type *f* for unit *u* (SF)

$GREEN_{fi}$ — green facility type *f* at installation *i* not used by currently stationed units (SF)

$OTHER_{fi}$ — other facility type *f* at installation *i* not used by currently stationed units (SF)

$Cost\_new_{if}$ — cost to maintain green-rated facilities of type *f* at installation *i* ($/SF)

$Cost\_sustain_{if}$ — cost to maintain other-rated facilities of type *f* at installation *i* ($/SF)

4. Variables

a. **Continuous Variables**

$agreen_{fi}$ — green conditioned SF of facility *f* available at installation *i* not used by currently stationed units (SF)

$erran_{ir}$ — deviation for range type *r* at installation *i* (day)

$milcon_{fi}$ — military construction of facility *f* at installation *i* (SF)

$upgrad_{fi}$ — conversion of facility *f* SF in other condition to green condition at installation *i* (SF)

$range_{ir}$ — number of range *r* to build at installation *i* (range)

b. **Binary Variables**

$exit_{fi}$ — 1 if units moved out of all 'other' category of facility *f* at installation *i*, and 0 otherwise

$station_{iu}$ — 1 if unit *u* is assigned to installation *i*, and 0 otherwise

$close_i$ — 1 if installation *i* is closed, and 0 if open

5. Formulation

a. Objective

Minimize:

$$
\begin{aligned}
&\sum_{iu} Vcost_{iu} * station_{iu} + \sum_{i} Fcost_i * (1 - close_i) \\
&+ \sum_{fi} MILCONcost_{fi} * milcon_{fi} + \sum_{i,r \in N} RNGcost_{ir} * range_{ir} \\
&+ \sum_{fi} UPcost_{fi} * upgrad_{fi} + \sum_{fi} Cost\_new_{if} * milcon_{fi} \\
&+ \sum_{if} (Cost\_new_{if} - Cost\_sustain_{if}) * upgrad_{fi} \qquad (1) \\
&+ \sum_{if} Cost\_sustain_{if} * FACcap_{if\,'other'} * (1 - close_i) \\
&+ \sum_{if} Cost\_new_{if} * FACcap_{if\,'green'} * (1 - close_i) \\
&+ \sum_{i,u \in UA_i - IS_i} MANcostM_u * station_{iu} + \sum_{i} MANcostC_i * close_i
\end{aligned}
$$

b. Constraint Sets

$$\sum_{u \in UA_i} FACreq_{fu} * station_{iu} \le \sum_{c} FACcap_{fic} + milcon_{fi} \quad \forall\ f\ i \qquad (2)$$

$$\sum_{u \in UA_i - IS_i} FACreq_{fu} * station_{iu} \le agreen_{fi} + GREEN_{fi} + milcon_{fi} + upgrad_{fi} \quad \forall\ f\ i \qquad (3)$$

$$agreen_{fi} + upgrad_{fi} \le OTHER_{fi} + \sum_{u \in IS_i} \sum_{i' \in CA_u - \{i\}} FACreq_{fu} * station_{i',u} \quad \forall\ f\ i \qquad (4)$$

$$FACcap_{fi\,"other"} * exit_{fi} \le upgrad_{fi} \quad \forall f\ i \qquad (5)$$

$$agreen_{fi} \le FACcap_{fi\,"green"} * exit_{fi} \quad \forall\ f\ i \qquad (6)$$

$$\begin{aligned}
&\sum_{u\in UA_i,\, i\in S1} RANrreq_{ru} * station_{iu} \le \sum_{i\in S1} (RANrcap_{ir} + erran_{ir}) \quad \forall r \\
&\sum_{u\in UA_i,\, i\in S2} RANrreq_{ru} * station_{iu} \le \sum_{i\in S2} (RANrcap_{ir} + erran_{ir}) \quad \forall r \\
&\sum_{u\in UA_i,\, i\in S3} RANrreq_{ru} * station_{iu} \le \sum_{i\in S3} (RANrcap_{ir} + erran_{ir}) \quad \forall r \\
&\sum_{u\in UA_i,\, i\in S4} RANrreq_{ru} * station_{iu} \le \sum_{i\in S4} (RANrcap_{ir} + erran_{ir}) \quad \forall r
\end{aligned} \tag{7}$$

$$\sum_{u\in UA_i} RANrreq_{ru} * station_{iu} \le RANrcap_{ir} + erran_{ir} \quad \forall r, i \in MT \tag{8}$$

$$\sum_{i} erran_{ir} \le moreRNGshort_r * RANrshort_r \quad \forall r \tag{9}$$

$$erran_{ir} \le MinRANGShort + RANm_r * range_{ir} \quad \forall\ i, r \in N \tag{10}$$

$$\begin{aligned}
&\sum_{i\in S1} erran_{ir} \le allowRNG_S1_r + ADDRNG_S1_r \quad \forall r \\
&\sum_{i\in S2} erran_{ir} \le allowRNG_S2_r + ADDRNG_S2_r \quad \forall r \\
&\sum_{i\in S3} erran_{ir} \le allowRNG_S3_r + ADDRNG_S3_r \quad \forall r \\
&\sum_{i\in S4} erran_{ir} \le allowRNG_S4_r + ADDRNG_S4_r \quad \forall r
\end{aligned} \tag{11}$$

$$\sum_{i\in CA_u} station_{iu} = 1 \quad \forall u \tag{12}$$

$$station_{iu} \le 1 - close_i \quad \forall i, u \in UA_i \tag{13}$$

$$\begin{aligned}
&\sum_{fi} MILCONcost_{fi} * milcon_{fi} + \sum_{i,\, r\in N} RNGcost_{ri} * range_{ir} \\
&\qquad + \sum_{fi} UPcost_{fi} * upgrad_{fi} \le maxMILCON
\end{aligned} \tag{14}$$

$$\sum_{i,u \in UA_u - IS_i} MANcostM_i * station_{iu} + \sum_i MANcostC_i * close_i \le maxMAN \qquad (15)$$

$$\sum_{fi} MILCONcost_{fi} * milcon_{fi} + \sum_{i,r \in N} RNGcost_{ir} * range_{ir} + \sum_{fi} UPcost_{fi} * upgrad_{fi} + \sum_{i,u \notin UA_u - IS_i} MANcostM_i * station_{iu} + \sum_i MANcostC_i * close_i \le maxCOST \qquad (16)$$

$$close_{i'} \le close_i \quad \forall i, i' \in DPD_i \qquad (17)$$

$$\begin{array}{r} agreen_{fi} \ge 0,\ milcon_{fi} \ge 0,\ upgrad_{fi} \ge 0 \quad \forall\ f\ i \\ erran_{ir} \ge 0,\ range_{ir} \ge 0 \quad \forall\ i\ r \end{array} \qquad (18)$$

$$\begin{array}{rcl} exit_{fi} & \in & \{0,1\} \ \forall\ f\ i \\ station_{iu} & \in & \{0,1\} \ \forall\ i\ u \\ close_i & \in & \{0,1\} \ \forall\ i \end{array} \qquad (19)$$

6. Constraint Sets Discussion

a. Facilities

Constraints (2) to (6) ensure facilities are available for assigned units; existing units use green-rated then other-rated facilities, and newly assigned units use extra green-rated, then other-rated (after upgrade), and then new MILCON.

Constraints (2) ensure the facilities required for each FCG for all units at each installation are within the available capacity and new MILCON.

Constraints (3) ensure the facilities for units that are new to an installation ($u \notin IS_i$) use MILCON and available existing facilities that are green–rated or upgraded to green-rated.

Constraints (4) to (6) ensure units vacate other-rated facilities at an installation before vacating green-rated facilities and that these other-rated facilities are upgraded for any newly stationed units.

b. Training

Constraints (7) to (11) constrain the stationing alternatives with respect to ranges.

Constraints (7) ensure that all units stationed at a consolidated set of installations have their training requirements met (by area and range).

Constraints (8) enforce a subset of the installations to satisfy each range requirements for stationed units.

Constraints (9) ensure for each type of range that the total shortfall cannot exceed some fraction of the starting shortage.

Constraints (10) ensure that new ranges are built to satisfy any shortfall for a subset of range types; however, a new range does not have to be built until a minimum shortage is attained.

Constraints (11) ensure that the allowable range shortfall by area is less than the shortfall prior to any realignment plus a possible addition over the original shortage.

c. Stationing Requirements

Constraints (12) ensure each unit is assigned to exactly one installation.

Constraints (13) ensure a stationing occurs only to an open installation.

d. Upfront Cost

Constraints (14) to (16) limit respectively MILCON, management, and total-one-time cost.

Constraints (17) ensure a dependent installation closes when its service providing larger installation closes.

e. Non-negativity

Constraints (18) declare the non-negative continuous variables of the model.

Constraints (19) declare the binary variables of the model.

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IV. COMPUTATIONAL EXPERIENCE

A. INTRODUCTION

With 51 installations and 194 units, OSAFK consists of about 7,000 constraints and 13,000 variables of which over 10,000 are binary. We implemented OSAFK using the General Algebraic Modeling System (GAMS) [GAMS Development Corporation 1998] and solved it using CPLEX Version 6.6.1 [ILOG CPLEX Division 2000]. Solution time is approximately four hours on a Pentium III computer when accepting the first solution guaranteed to be within ten percent of optimal.

Implementing OSAFK requires extensive data of the variety introduced in the preceding chapters. These data are available from standard US Army sources and supporting models. However, the limited data set provided had some conflicts and required some interpretation before use.

The fixed and variable cost for installations in South Korea was not provided. A data set for installations used in OSAF runs was available [Tarantino 2001]. From the available OSAF data, we calculate the average of the BOS costs and round them to $40,000,000 fixed and $4,000 variable. We apply these averages to all installations in South Korea, regardless of their size.

The sustainment costs for green-rated and other-rated facilities also need interpretation. A set of data for total sustainment cost of permanent and non-permanent installations are provided [Bassichis 2001]. Using these costs as a basis, we derive a cost to sustain green and other rated facilities for each FCG group (Table 5).

FCG Description	Yearly green-rated sustainment cost	Yearly other-rated sustainment cost
OPERATIONS / ADMINISTRATIVE	3.24 ($/square foot)	4.47 ($/square foot)
AVIATION MAINTENANCE	1.59 ($/square foot)	2.59 ($/square foot)
VEHICLE / DOL MAINTENANCE	1.90 ($/square foot)	2.33 ($/square foot)
SUPPLY / STORAGE	1.47 ($/square foot)	2.03 ($/square foot)
TRAINING / INSTRUCTION (ACTIVE)	2.38 ($/square foot)	3.34 ($/square foot)
COMMUNITY FACILITIES	2.76 ($/square foot)	2.99 ($/square foot)
FAMILY HOUSING	2.20 ($/square foot)	3.00 ($/square foot)
ENLISTED UPH	387.12 ($/unit)	662.37 ($/unit)
OFFICER UPH	387.12 ($/unit)	662.37 ($/unit)
NCO UPH	387.12 ($/unit)	662.37 ($/unit)
AT/MOB SPACES	387.12 ($/unit)	662.37 ($/unit)
AMMUNITION STORAGE	1.86 ($/square foot)	2.03 ($/square foot)
BULK FUEL STORAGE	0.08 ($/gallon)	0.10 ($/gallon)

Table 5. Sustainment Costs for Green-rated and Other-rated Facilities.

We had relatively complete data for 48 installations but not for Camp Chunchon, Pyong Complex and Wonju Residence installations. For purposes of the results presented here, we consider these three installations closed.

We analyze OSAFK results when restricting the one-time (upfront) cost. The upfront cost without moving any units is a little less than $5.5 billion; this cost primarily accounts for MILCON necessary to build facility square feet required but currently unavailable to the units. Although no new range construction and sustainment cost is added to this figure, it is obvious that this number captures a large part of the $7 billion anticipated for MILCON as described by Schwartz [2001]. OSAFK recommends the closure of seven installations with only garrison units because we assume garrison units do not move.

B. RESULTS

OSAFK provides the optimal stationing of units that minimizes the 20-year Net Present Value (NPV) cost (equation (1) using the same discount rate found in OSAF) while observing all the conditions specified in equations (2) to (19). We examine how the 20-year NPV changes under different values of upfront cost and observe that a little increase in these upfront costs provides substantial reduction to the NPV (Figure 2). By analyzing these alternatives in more detail, we have noticed that the primary reduction to the NPV is the fixed cost associated with having an installation open.

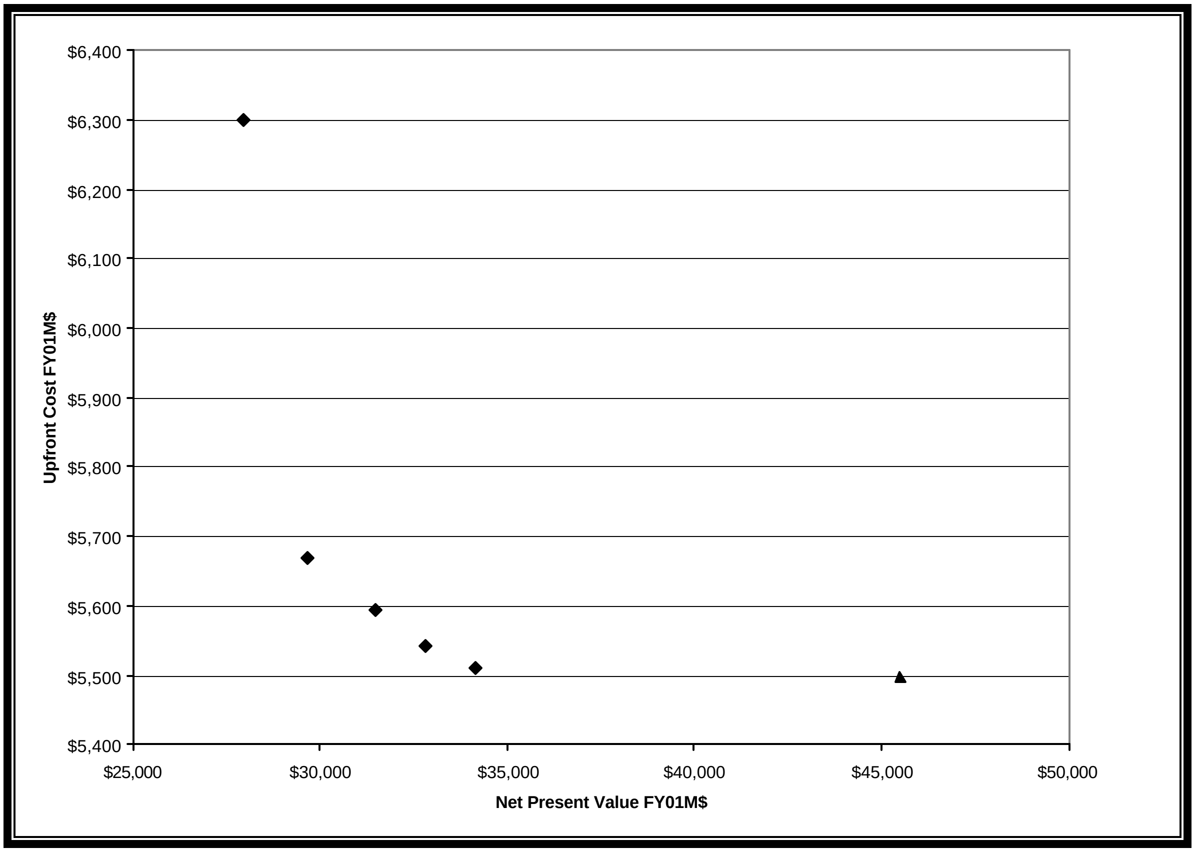

Figure 2. Net Present Value with Changing Upfront Cost. The triangle indicates the status quo solution obtained without moving any units. By slightly increasing upfront cost above levels required by the status quo, we see a significant (over $11 billion) reduction to the 20-year net present value.

Figure 3 shows the number of installations closed with different upfront costs. With just a small increase above the upfront cost ($5.5 billion) needed to provide adequate facilities, OSAFK recommends a large number of installation closures and a corresponding large number of unit movements (over half of all units). This recommendation suggests the benefit (over $11 billion reduction to the 20-year NPV) of an extensive MILCON program on a comparatively smaller number of installations (with smaller fixed costs). Management cost (Figure 4) for both closing installations and moving units is only a minor contribution to the total cost. The majority of the upfront cost is MILCON.

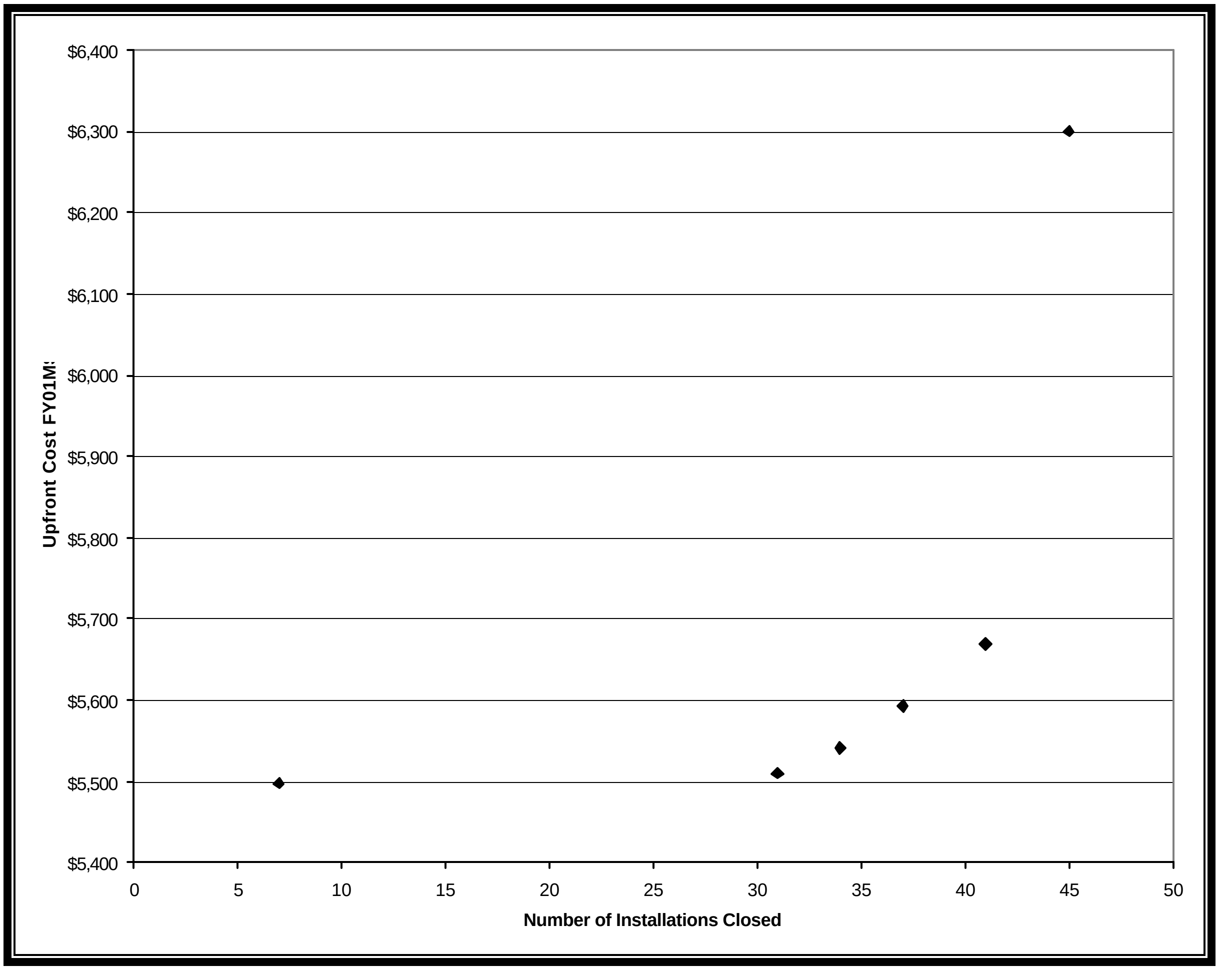

Figure 3. Number of Installations Closed Under Different Levels of Upfront Cost.

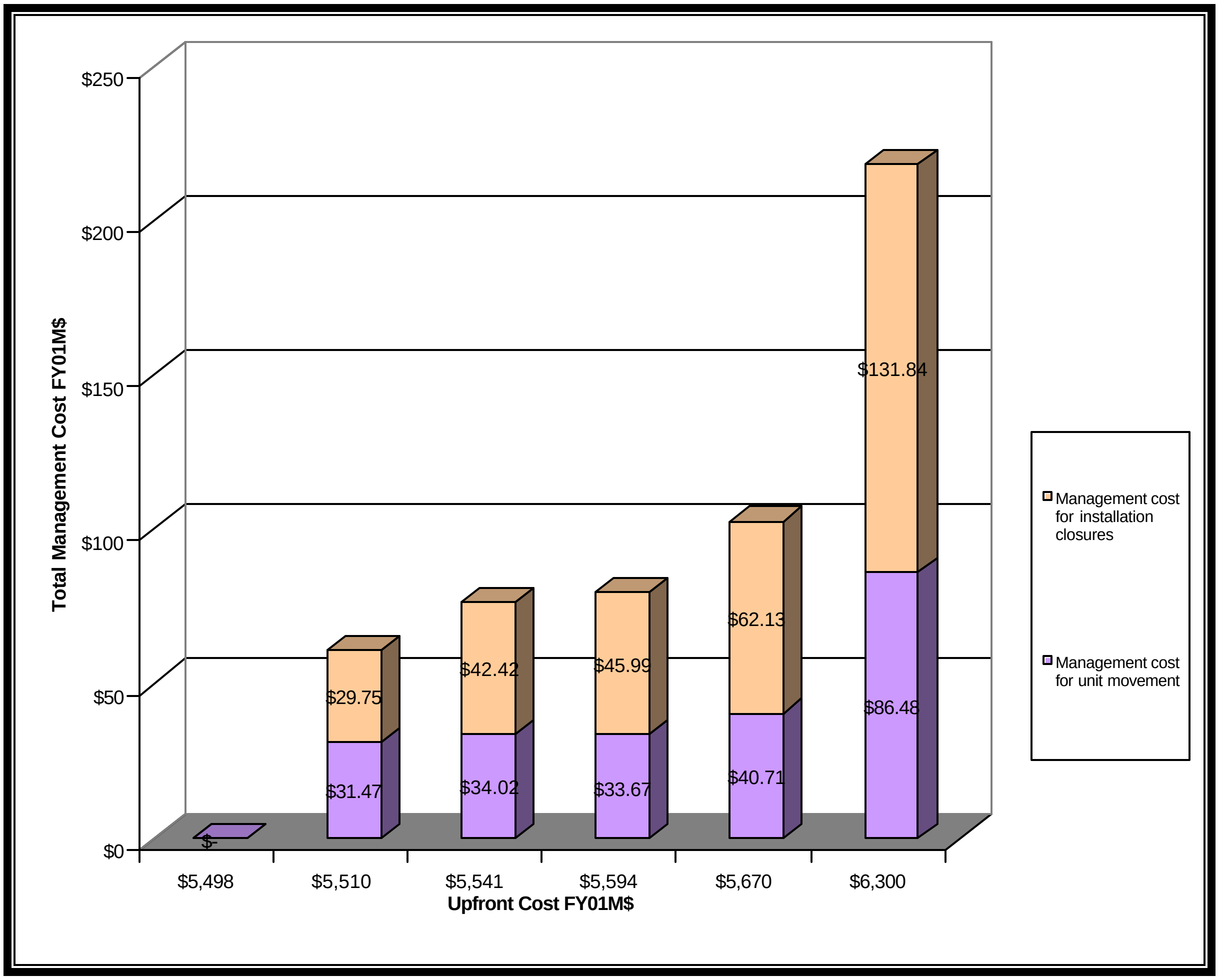

Figure 4 Management Cost for OSAFK Recommended Closures. The management costs is only a small portion of the upfront cost. MILCON is most of the upfront cost.

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V. CONCLUSIONS

OSAFK is an integer linear program that enables a systematic examination of US Army stationing alternatives and prescribes an optimal US Army stationing plan for a given set of units and installations while observing budgetary restrictions and stationing policies. OSAFK is based on the integer linear program, OSAF (Optimal Stationing of Army Forces) that was developed to help recommend closure and realignment recommendations for installations located in the US. This thesis modifies OSAF to study the restationing of US units and closure of US installations in South Korea. OSAFK introduces the idea of dependent installations that must be closed when their supporting installation closes. It also relies on an area restriction where unit stationing is restricted to one of four support areas.

Using the limited data set available for our study, we find a significant shortage between infrastructure required by US Army units currently stationed in South Korea and available infrastructure. Our results indicate it would require just under $5.5 billion to provide adequate facilities for US Army units for just the 27 facility FCGs we consider. With just a small increase above this $5.5 billion, OSAFK recommends a large number of installation closures. Under our assumed cost structure, this recommendation suggests the benefit (over $11 billion reduction to the 20-year net present value cost) of an extensive MILCON program on a comparatively smaller number of installations.

After enhancing OSAFK with more realistic training and cost data, we recommend the US Army use OSAFK to help guide the closure and realignment of its installations in South Korea.

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APPENDIX

Figures A1 and A2 show the location of US installations in the Northern and Southern halves of South Korea

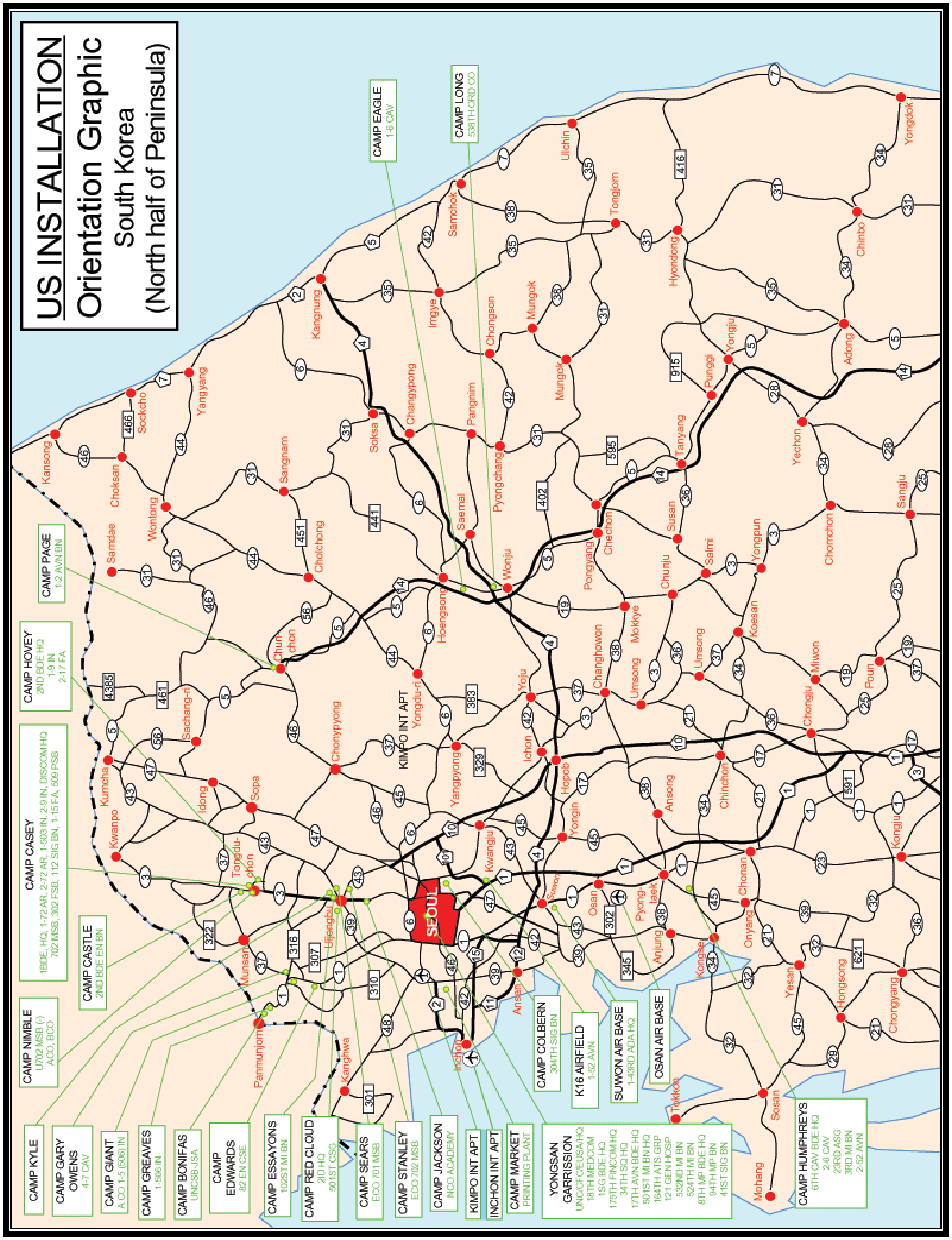

Figure A1. US Installations in South Korea (Northern half of the Peninsula). [from US Department of the Army 2001e]

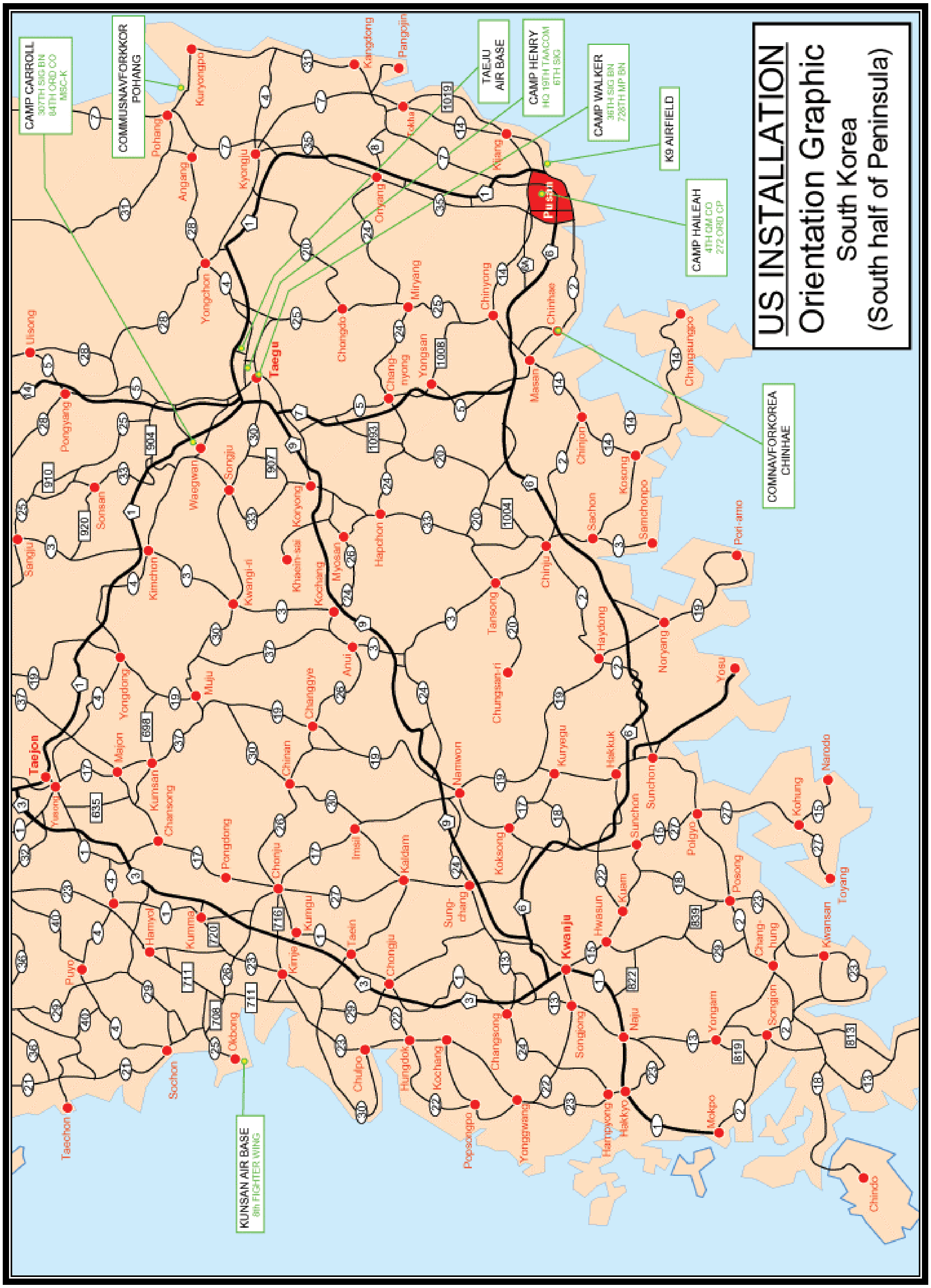

Figure A2. US Installations in South Korea (Southern half of the Peninsula). [from US Department of the Army 2001e]

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