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Optimal load lists of ordnance for the AE-26 class ammunition ship.

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NAVAL POSTGRADUATE SCHOOL
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THESIS

OPTIMAL LOAD LISTS OF ORDNANCE FOR THE
AE-26 CLASS AMMUNITION SHIP

by

John K. Rowland

September 1988

Thesis Advisor: Dan C. Boger

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Optimal Load Lists of Ordnance for the AE-26 Class Ammunition Ship

by

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ABSTRACT

This study provides alternative optimal ordnance load lists for the AE-26 class ammunition ship in a station ship role. A survey questionnaire was developed based on a wartime scenario. The questionnaire was administered to 40 Naval officers, who were asked to prioritize various ordnance types in the order of their contributions to the mission described in the scenario. The survey results, along with a linear optimizing equation and equations based on several real-world constraints, were used as input into a linear program. Sensitivity analysis was performed by substituting other nonlinear optimizing equations for the objective function in the program, and observing the changes in the ordnance load lists. Inherent advantages and disadvantages of the various objective functions, reflected in the optimal load lists, were noted, and are described in detail.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research have not 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.

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LIST OF ABBREVIATIONS

AAW - air-to-air warfare

AE - ammunition ship

AE-26 - Kilauea class ammunition ship

AFS - stores ship

AO - oiler

AOE - fast combat support ship

AOR - fleet replenishment oiler

ASUW - anti-surface warfare

ASW - anti-submarine warfare

CBG - Carrier Battle Group

CG-26 - Belknap class cruiser

CG-47 - Ticonderoga class cruiser

CGN-38 - Virginia class nuclear powered cruiser

CLF - Combat Logistics Force

CVN - nuclear powered aircraft carrier

DD-963 - Spruance class destroyer

DDG-993 - Kidd class destroyer

GAMS - General Algebraic Modeling System

LAMPS - Light Airborne Multi-purpose Weapons System

NPS - Naval Postgraduate School

UNREP - underway replenishment

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I. INTRODUCTION

A. BACKGROUND

An April 1988 Congressional Budget Office study on the U. S. Navy's Combat Logistics Force (CLF) analyzes the issues and options for the Navy's CLF and is the primary reference for this section [Ref. 1]. The Navy's push for 600 ships in the 1980s has resulted in a total of 15 deployable Carrier Battle Groups (CBGs) that will require a tremendous amount of resupply from the CLF ships during a global war. The CLF ships are responsible for supplying the battle groups with ammunition, stores, spare parts, and fuel at sea by conducting underway replenishments (UNREPs). The five ship types in the CLF are the fast combat support ships (AOEs), fleet replenishment oilers (AORs), oilers (AOs), stores ships (AFSs), and the ammunition ships (AEs).

The ships of the CLF can be divided further into station ships and shuttle ships. The primary mission of the AOEs and AORs is to act as station ships for the CBG. The station ship serves as an integral part of the battle group that must stay within close proximity of the combat ships to conduct UNREPs whenever required. The station ship is an emergency source of resupply of multiple products for the CBG. The shuttle ships consist of the AOs, AFSs, and AEs. These shuttle ships are designed to carry only single products such as fuel, food and dry goods (stores), or ammunition, unlike the station ships that must carry all of these products.

A major concern of the Navy is the resupply of ordnance for the CBGs in time of war. The Navy currently has four AOEs that each have an ordnance stowage capacity of approximately 300,000 cubic feet. The seven AORs each have only approximately 65,000 cubic feet of ordnance stowage capacity. The 11 AOE and AOR station ships in the fleet today obviously cannot meet all the wartime ordnance requirements for 15 CBGs. There are plans to build more AOEs and AEs in the 1990s, but the Navy must make the best use of its available CLF ships to provide an adequate capability to resupply ordnance to the battle groups in time of war.

The ammunition ship is the other ship in the CLF inventory that has a significant ordnance stowage capacity. There are currently 13 AEs, each capable of carrying approximately 340,000 cubic feet of ordnance. The AEs will serve two different missions during wartime. The primary mission will be serving as a shuttle ship to distribute ordnance on a push basis from forward ports to the CBGs. The secondary mission of the AEs will be acting as battle group station ships, similar to the AOEs and AORs, to deliver ordnance to the battle group on a pull basis. [Ref. 2:p.3,4] The pull system requires the station ship to have sufficient levels of all ordnance to supply to the CBG upon request, and the push system allows the shuttle ships to push available ordnance forward to the CBG.

Logistics considerations dictate that an AOE or AOR multi-product station ship should be a part of each CBG because of the station ship's ability to resupply all types of products. However, the AOE capacity can be matched for all products by using AEs and AORs as station ship pairs to resupply the battle group.

The resupply of ordnance to the battle groups at sea may be described as a three phase transportation network. Merchant ships transport ordnance from the United States to forward bases in phase one. Ordnance is consolidated and taken from the forward bases to the battle group station ships by the single product shuttle ships in phase two. Station ships then UNREP the ordnance to the combat ships in the third and final phase.

The shuttle ships also have the capability to act as station ships for the battle groups if required. The advantage of having station ships UNREP the battle group is a reduced alongside time because the station ship can transfer all products at the same time. This increases the amount of time the CBG can engage the enemy and decreases the CBG vulnerability to damaging attacks that could coincide with the UNREPs. Station ships also allow the CBG to extend the amount of time that it can remain on station conducting strike operations by relieving the need for the battle group to steam to the forward bases for resupply.

The class of ship examined in this study was the AE-26 class ammunition ship. The AE-26 has 14 separate ordnance stowage compartments. The configuration consists of four holds that each contain a main deck, second deck, first platform, and second platform -- except for the first hold that only contains a first and second platform. Hold number one is forward and hold number four is aft. The location of hold number one is important because this forward hold must be filled with the heaviest ordnance in order to keep the bow of the ship down into the water for sea keeping purposes.

The AE-26 class ammunition ship uses the advanced diagonal metal dunnage system to provide a secure method for the stowage of ordnance. The deck space is divided into blocks that can accommodate almost all ordnance dimensions. A deck track is placed at a 45 degree angle to the centerline of the ship. Portable aluminum stanchions are inserted vertically in holes in the deck and in the overhead. Horizontal stanchions are secured with a chain and hook to the vertical stanchions to make a rectangular structure to store ordnance. The amount of wood dunnage used to block and brace the aluminum structure is minimal. The advantage of the diagonal metal dunnage system is that it uses the deck space very efficiently without wasting valuable ordnance stowage space. [Ref. 2:p.16]

B. THESIS MOTIVATION

The motivation for this thesis is the fact that the Navy does not have enough CLF ships to resupply all the CBGs with ordnance in time of war. The AEs and AOEs planned for production (that manage to survive budget cuts) will not eliminate the shortage of CLF ships that can contribute a significant resupply of ammunition to the CBGs during war. A more effective method of determining load lists for these ships would help to reduce the shortage in ordnance resupply capability.

A model that provides a load list based on the mission of the CBG, threat to the CBG, and ordnance stowage capacity of the ammunition ship would increase the probability that there will be a proper mix of ordnance on the station ship for the CBG. The current load lists for the CLF ships are highly dependent on the previous ordnance loadout of the ship. Modifications to the station ship load lists are made by the individual battle group ships, but this may not provide the best mix of weapons for the battle group in time of war.

C. OBJECTIVES

The objective of this thesis is to develop alternative optimal load lists of ordnance for the AE-26 class ammunition ship in a station ship role. A wartime scenario has been developed for use in a survey to demonstrate the model. Survey forms were distributed to experts who were asked to evaluate the contribution of each of 17 kinds of ordnance to mission effectiveness for a specified CBG. The survey was conducted at the Naval Postgraduate School (NPS) and at various Navy commands responsible for Naval ordnance tactics in order to elicit expert opinion on the prioritization of these types of ordnance.

The survey description and results are given in Chapter II. A ten-step procedure developed by Lindsay was used to obtain scaled values for the ordnance types from the categorical judgements obtained via the survey [Ref. 3]. The ten-step procedure is included with examples in Chapter III. A linear programming model then was developed to determine an optimal load list for the AE-26, given the prioritization of ordnance based on the survey and the constraints of the ship to store ordnance. The linear program is described in Chapter IV and the summary of results and conclusions is provided in Chapter V.

D. SCOPE OF STUDY

This study has been limited to ordnance loads consisting mostly of threat ordnance rather than level of effort ordnance. Threat ordnance is sophisticated and expensive "smart" weapons, while level of effort ordnance refers to inexpensive "dumb" weapons such as bullets. Threat ordnance usually is made up of long lead time items that are designed to counter a specific threat. The level of effort ordnance is not designed to counter a specific threat, but may be used in a wide variety of missions at a higher expenditure rate than threat ordnance.

The results are also limited to the general wartime replenishment scenario used in the survey. However, the methodology used is robust in handling any positive-number weighting scheme that a decision maker may choose for prioritizing ordnance.

The resulting load list must be reviewed and modified for any deficiencies in levels of ordnance. The load list should also be checked for feasibility by the person in charge of planning the AE loadout in order to ensure ordnance compatibility and ship stability, and to meet other stowage constraints not modeled.

The model will not provide a final answer for an ordnance load list for any contingency. However, it can be used to provide a good estimate of an optimal ordnance load list for the AE-26.

II. SURVEY

Ammunition ships are currently loaded with ordnance on the basis of the previous load list for a particular ship. The load list is a document that lists the variety and quantity of various products to be carried by each logistic ship for resupply and maintenance support of the battle group. The load list is updated by the ships in the battle group for any obvious deficiencies in the types and amount of ordnance to be carried.

There are currently no models for determining optimal ordnance load lists for the logistics ships in time of war. The load lists for the ammunition ships will be highly dependent on the ordnance usage rates of the battle groups once hostilities have begun. However, plans must be made now to determine how specific ships are going to be loaded for various missions, to ensure that effective ordnance mixes are available for the CBGs from the existing ordnance stockpiles. A war would provide the answer to the question of which ordnance types are most important to have on the CLF ships. Fortunately, there are ways short of an actual war to estimate mixes of ordnance that would be of most use to the CBGs.

One of the better methods to estimate the uncertainty in the prioritization of ordnance is to survey experts. Experts in the context of this study means Naval officers familiar with the tactical employment of naval ordnance. A carefully worded questionnaire allows experts the opportunity to use their experience and judgement in deciding which ordnance types are more important to have for resupply of the battle group.

This issue is important because the Navy does not have enough CLF ordnance stowage capacity to supply the ordnance required by 15 CBGs in a global war. Tradeoffs will have to be made in loading the existing CLF ships with ordnance because of their limited capacity and limited number of ships available. Some types of ordnance are obviously more important to the battle group in terms of power projection, defending sea lines of communication, and defending the battle group.

A. SURVEY METHODOLOGY

The survey instructions, Appendix A, and the survey, Appendix B, were designed to provide a method to determine a prioritization of ordnance to be loaded on an AE-26 class ammunition ship. The survey format was based on one developed by Guadalupe [Ref. 4]. The forms were distributed to Naval officers in various warfare specialties at NPS, and to operational experts in naval ordnance such as weapons officers on aircraft carriers and tactical training groups.

A categorical method was used to elicit preferences between various types of ordnance at the recommendation of survey experts at NPS. The categorical method was also used because of the relative ease with which personnel can respond to this kind of survey [Ref. 5:p.10]. The categories used to prioritize the ordnance were

1. very low,
2. low,
3. medium,
4. high, and
5. great contribution to CBG mission accomplishment.

1. Scenario

The wartime replenishment scenario was designed to be specific enough to allow the rater to respond in a particular category for each ordnance type in the survey. The scenario was also kept somewhat general in the sense that it is easy to change the CBG composition, mission, and threat to reflect any situation that a particular battle group may face in wartime.

The mission of the AE-26 class ship is to provide ordnance to the battle group as required. Its contribution to CBG mission accomplishment was chosen to be the measure of effectiveness for each ordnance type included in the survey.

2. Ordnance

The survey form listed 17 types of ordnance for evaluation by the rater, who responded with a mark in the appropriate category for each. The AE-26 class has hundreds of ordnance types in inventory, a quantity deemed beyond the scope of this study. The list of ordnance was narrowed down by choosing mostly threat ordnance for evaluation. The specific ordnance types used in the survey are given in Appendix B.

B. RATER QUESTIONNAIRE STATISTICS

A total of 40 of the 47 survey forms sent out were completed and returned by the experts. The response to the surveys was very positive and helpful in conducting a meaningful analysis. The rater questionnaire, Appendix C, provided information about the person completing the survey as well as comments about the survey. The 40 returned surveys were completed by 20 officers at NPS and 20 officers from the fleet.

The 20 NPS surveys included inputs from 12 lieutenants and eight lieutenant commanders. The average number of years spent on active duty by officers in the NPS survey was 9.8 years, with an average of 1.3 years on staff duty.

The 20 fleet surveys were completed by four lieutenants, five lieutenant commanders, eight commanders, and three captains, with an average of 20.2 years active duty. The officers in the fleet survey had an average of over 10 more years of Navy experience than the officers from NPS. The fleet officers also had a higher average time spent on staff duty, 2.4 years.

A total of 38 of the 40 surveys returned indicated that the scenario presented in the survey was understandable. One officer desired a more specific definition of who the enemy was for the mission. The officer assumed Soviet forces in responding to the survey. Another officer wanted a better description of the targets to be selected in the air strike. The reason for that request is that an ordnance type can be chosen with more confidence if there is a great deal of information concerning the target. This information was not given in the survey because the exact targets for a strike force will not be known until after a decision is made to load the ammunition ships for war.

Almost all of the officers completing the survey reported that the ordnance types listed in the survey were representative of the priority items a CBG must have in order to carry out its mission. Many officers also listed other ordnance that could be included in the list of priority ordnance. The most mentioned items to add to the ordnance load list were laser guided bombs, sonobuoys, 20-mm rounds for the Vulcan Phalanx gun, and the Talos missile.

More specific comments about ordnance were also made. Some officers thought that the ordnance could have been broken down into different types such as the Tomahawk anti-ship missile and the Tomahawk land-attack missile. Some officers claimed that smart weapons would be used more than iron bombs to conduct air strikes because of the smart weapon's ability to attack targets with great accuracy.

Anti-air warfare ordnance was also high on the list of priority ordnance as well as anti-submarine warfare ordnance.

A few general comments were made concerning the survey. It was noted that frigates were not included in the CBG. The reason for excluding the frigates from the wartime CBG was that they will probably be used to escort merchant ships during war. Others mentioned that enemy capabilities and environment were important factors in selecting ordnance mixes. This is true when loading ships and aircraft in preparation for attacks, but these factors again will be unknown when the ammunition ships are initially loaded out.

C. RAW FREQUENCY DATA FOR NPS SURVEY

The raw frequency data compiled from the survey responses of the 20 Naval officers from NPS are provided in Table 1. The 17 ordnance types are listed down the left column and the categories of contribution to mission accomplishment to the CBG are across the top. The HARM missile and the MK-46 torpedo received the highest scores in the survey. HARM is a high speed air to surface anti-radar missile which can knock out enemy radars from approximately 80 nautical miles preceding an air strike. The MK-46 torpedo is a high speed, deep diving torpedo that can be launched from surface vessels, fixed-wing aircraft, or helicopters. The five-inch projectile, a short range weapon used aboard surface ships against air and surface targets, received the lowest score.

TABLE 1. RAW FREQUENCY DATA FROM NPS OFFICERS

F_{ij}	VERY LOW	LOW	ME-DIUM	HIGH	GREAT
SIDEWINDER	0	2	7	7	4
1000 LB BOMB	0	6	5	8	1
HARPOON	4	6	7	2	1
MK46	0	0	2	11	7
PHOENIX	2	2	6	8	2
ROCKEYE	1	5	6	6	2
5" PROJECTILE	5	5	6	3	1
TOMAHAWK	4	6	3	6	1
SHRIKE	2	2	4	7	5
SEASPARROW	1	7	9	2	1
2000 LB BOMB	3	3	10	3	1
STANDARD	0	8	7	3	2
WALLEYE	2	4	6	7	1
500 LB BOMB	2	2	7	5	4
HARM	0	0	5	7	8
SPARROW III	0	4	11	4	1
ASROC	2	2	3	9	4

D. RAW FREQUENCY DATA FOR FLEET SURVEY

The compiled results of the survey for the 20 Naval officers responding from the fleet are shown in Table 2.

TABLE 2. RAW FREQUENCY DATA FROM FLEET OFFICERS

F_{ij}	VERY LOW	LOW	MEDIUM	HIGH	GREAT
SIDEWINDER	0	2	9	2	7
1000 LB BOMB	0	0	1	13	6
HARPOON	0	4	9	6	1
MK46	0	0	5	4	11
PHOENIX	0	0	8	5	7
ROCKEYE	0	3	2	13	2
5" PROJECTILE	5	7	4	3	1
TOMAHAWK	1	4	6	4	5
SHRIKE	0	4	8	6	2
SEASPARROW	2	9	6	2	1
2000 LB BOMB	2	3	7	6	2
STANDARD	3	4	5	6	2
WALLEYE	1	3	9	4	3
500 LB BOMB	0	4	9	5	2
HARM	1	0	2	7	10
SPARROW III	0	1	7	9	3
ASROC	1	4	5	4	6

Once again the HARM anti-radar missile and the MK-46 torpedo received the highest scores and the five-inch projectile received the lowest score. The rankings are very similar to the rankings of the NPS survey for many of the ordnance types. This was expected because the Naval officers at NPS make up for their lower level of experience via a good understanding of naval ordnance shared by the fleet.

E. SURVEY ANALYSIS

The raw data tables from each survey group were used to set up a contingency table analysis for each ordnance type.

A contingency table is a table where each observation is classified in two or more ways. The null hypothesis tested is that the two criterion variables are independent. The criterion variables are officer source, NPS or the fleet, and ranking of the ordnance. The null hypothesis claims that there is no difference in survey responses with respect to NPS versus fleet officers.

The chi-square goodness-of-fit test is used to test the null hypothesis at an alpha level of 0.05. The chi-square test is appropriate for nominal and ordinal level of data as well as interval and ratio level data [Ref. 5]. The chi-square test statistic is computed by the following equation:

$$Q = \sum \frac{(f_o - f_e)^2}{f_e} \quad (2.1)$$

The values used for f_o and f_e are the observed and expected frequencies for each cell in the contingency table. The frequencies are summed for all rows and columns of the contigency table. The larger the value of Q, the larger the difference between the observed and expected frequencies. The null hypothesis is rejected if Q is larger than k, where k is the critical value of the chi-square distribution for (R-1) times (C-1) degrees of freedom and a $1-\alpha$ confidence level. R is the number of rows and C is the number of columns in the contingency table.

A chi-square contingency table analysis for the 1000-pound bomb is given as an example. The contingency table is provided in Table 3.

TABLE 3. CONTINGENCY TABLE FOR THE 1000 LB BOMB

- -	VERY LOW TO MEDIUM		HIGH		GREAT		TOTAL OBS
	OBS	EXP	OBS	EXP	OBS	EXP	
FLEET PARTICIPANTS	1	6	13	10.5	6	3.5	20
NPS PARTICIPANTS	11	6	8	10.5	1	3.5	20
TOTAL PARTICIPANTS	12		21		7		40

The observed frequencies (OBS) are on the left side of each cell, and the expected frequencies (EXP) are on the right side. Each expected frequency is calculated by multiplying the corresponding row sum by the column sum, then dividing by the grand total. For example, the expected frequency for the upper left cell is 6: 20 times 12 divided by 40. The chi-square statistic, Q, is found to be 13.1, using the chi-square equation, Equation 2.1. The critical value of the chi-square distribution, k, is found from a standard chi-square table using a 0.95 (1-0.05) confidence level and 2 (2-1 times 3-1) degrees of freedom. The null hypothesis is rejected in this case since Q = 13.1, which is greater than k (k = 5.991).

It is recommended that cells be combined when more than 20 percent of the total number of cells have a calculated expected frequency value that is less than 5 [Ref. 5]. This has been done in the above example. The value of Q tends to decrease when the cells are combined since the values in the denominator of the chi-square equation increase. The null hypothesis will be accepted more often when the value of Q decreases since the null hypothesis is rejected for Q greater than k. However, even after combining the high and great category cells, the null hypothesis is still rejected in this example because Q = 12.0, which still is greater than k (k = 3.841).

The results of the chi-square test for all ordnance types are provided in Appendix D. The results show that the null hypothesis is rejected for only one of the 17 ordnance types. The rejected case was the 1000-pound bomb, that is, the example shown in Table 3. In this case there was a significant difference between the way the officers at NPS and the fleet responded to the survey.

The chi-square test statistic was less than k for all other ordnance types. This result indicates that there was no significant difference between the survey responses at NPS and the fleet at an alpha level of 0.05. Any diffences in the responses between the two survey groups are due to sampling or random chance for all ordnance types except the 1000-pound bomb.

III. SCALING

A. INTERVAL SCALE CONSTRUCTION FROM CATEGORICAL JUDGEMENTS

The data gathered from the survey were scaled using the experts' categorical ratings and a ten-step procedure for obtaining scale values from such categorical judgements. This method was selected based on its successful use by Crawford in a similar study [Ref. 6]. The Lindsay ten-step procedure [Ref. 3] constructs an interval scale that includes the instances and the bounds between the categories. In this case, instances are the ordnance types which make up the rows of the frequency array, while the categories of contribution to mission accomplishment make up the columns, as illustrated in Chapter II, Tables 1 and 2.

Five categories are usually used, with no assumptions made concerning relative interval sizes of the categories. The categories are also a mutually exclusive set of intervals that collectively exhaust the continuum.

The ten-step method requires several assumptions. The first assumption is that the rater's judgements about the scale value of an instance i can be expressed as a normally distributed random variable with mean μ_j and variance σ_j^2.

The second assumption is that raters view the continuum of values for instances as categories that are broken into successive intervals, each having an upper bound or boundary. The rater's judgement about the category's upper bound is also expressed as a normally distributed random variable. Category j has a normally distributed upper bound with mean μ_j and variance σ_j^2 .

The third assumption is that the rater's judgements about the scale values of instances are stochastically independent random variables that have a correlation coefficient of zero for all pairs i and j.

The fourth assumption is that all category bounds have the same variance, that is, V_j^2 = c for all j. [Ref. 3]

B. TEN-STEP PROCEDURE FOR OBTAINING SCALE VALUES

The ten-step procedure described below is taken from Reference 3. It is a method that yields scaled numerical data for raters' categorical responses concerning the ordnance types. The scaled data then are used as input to the objective function of the linear program described in Chapter IV.

1. Arrange the raw frequency data in a table Fij where the rows are instances i and the columns are categories j. The columns should be arranged in ascending order of category value, so that the last column to the right represents the most favorable category.

2. Compute relative cumulative frequencies for each row, and record these in a new table Pij where Pij is the the proportion of raters judging instance i in or below category j. The values in the right hand column of Pij will always be one and may be omitted for computational purposes.

3. Compute the Zij array by treating the Pij values as leftward areas under a Normal (0,1) curve and find the Z values for these areas in a table of values of the normal or Gaussian distribution.

4. Compute the row average $\bar{Z}_i$ for each row i in the Z_{ij} array.

5. Compute the column average bj for each column j in the Zij array. The bj column averages are the upper bound values of category j on the scale.

6. Compute the grand average $\bar{b}$ of all the values in the Zij array. This is done by averaging the column averages bj.

7. Compute the sum of squares for the column differences

$$B = \sum_{j=1}^{m-1} (b_j - \bar{b})^2 .$$

8. Compute the sum of squares of the row differences

$$A_i = \sum_{j=1}^{m-1} (Z_{ij} - \bar{Z}_i)^2 .$$

9. Compute $\sqrt{(B/A_i)}$ for each row to give an estimate of $\sqrt{(\sigma_i^2 + c)}$.

10. Compute $S_i = \bar{b} - \bar{Z}_i\sqrt{(B/A_i)}$ for each row i. The Si values are the scale values of the instances, and are on the same interval scale as the category bounds bj. A linear transformation $Y = \alpha + \beta x, \beta > 0$, may be performed to move the scale where it is desired. The same transformation must be used to move the instance values and the category bounds.

C. OBTAINING SCALE VALUES FROM THE CATEGORICAL SURVEY DATA

1. Example of Procedure

An example of the ten-step procedure for the fleet survey will be shown step by step. The scaling problem is broken into different problems because the Zij array must be complete, as described in Reference 3.

1. The raw frequencies are given as illustrated in Table 4. The categories V, L, M, H, and G represent very low, low, medium, high, and great contribution to CBG mission accomplishment for the ordnance type in each row.

TABLE 4. FLEET RAW FREQUENCY DATA FOR PROBLEM 1

F_{ij}	V	L	M	H	G
1000 LB BOMB	0	0	1	13	6
PHOENIX	0	0	8	5	7
MK46	0	0	5	4	11

2. The relative cumulative frequencies are computed for each row, as illustrated in Table 5. The last column will always be a vector of ones and may be omitted.

TABLE 5. RELATIVE CUMULATIVE FREQUENCY DATA

P_{ij}	V	L	M	H
1000 LB BOMB	0	0	.05	.7
PHOENIX	0	0	.4	.65
MK46	0	0	.25	.45

The values given in Table 5 may be compressed into a four-cell table, Table 6, because none of the experts selected the very low or low category for any of these three weapons.

TABLE 6. COMPRESSED RELATIVE FREQUENCY DATA

P_{ij}	M	H
1000 LB BOMB	.05	.7
PHOENIX	.4	.65
MK46	.25	.45

3. The relative frequencies are then treated as leftward areas under a Normal (0,1) curve. The z values for the areas are recorded in Table 7.

TABLE 7. Z VALUES FOR THE NORMAL DISTRIBUTION

Z_{ij}	M	H
1000 LB BOMB	-1.645	.524
PHOENIX	-.253	.386
MK46	-.675	-.126

4. The row averages, $\bar{Z}_i$, are computed, as shown in Table 8.

5. The column averages, b_j, are also computed in Table 8.

TABLE 8. ROW AND COLUMN AVERAGES

Z_{ij}	M	H	$\bar{Z}_i$
1000 LB BOMB	-1.645	.524	-.561
PHOENIX	-.253	.386	.067
MK46	.675	-.126	-.401
b_j	-.858	.261	-

6. The grand average, $\bar{b}$, is computed. For this example, that calculation is:

$$\bar{b} = (-0.858 + 0.261)/2 = -0.298 \ .$$

7. The sum of squares of the column averages, B, is calculated:

$$B = \sum_{j=1}^{m-1} (b_j - \bar{b})^2 \ .$$

$$B = (-0.858 - (-0.298))^2 + (0.261 - (-0.298))^2$$

$$B = 0.3136 + 0.312 = 0.626$$

8. The sum of squares of the row averages is calculated for each row of the Zij array.

$$A_i = \sum_{j=1}^{m-1} (Z_{ij} - \bar{Z}_i)^2 \ .$$

A_1 = $(-1.645-(-0.561))^2 + (0.524-(-0.561))^2$ = 2.352

A_2 = $(-0.253-(0.067))^2 + (0.386-(0.067))^2$ = 0.2042

A_3 = $(-0.675-(-0.401))^2 + (-0.126-(-0.401))^2$ = 0.151

9. The value of $\sqrt{(B/A_i)}$ is calculated for each row:

$(0.626/2.352)^{.5}$ = 0.516

$(0.626/0.2042)^{.5}$ = 1.751

$(0.626/0.151)^{.5}$ = 2.036

10. The scale values of the ordnance types are given for each row by the formula:

$$S_i = \bar{b} - \bar{Z}_i\sqrt{(B/A_i)}$$

The values for the S_is are as follows:

S_1 = -0.298 - (-0.561)(0.516) = -0.00852

S_2 = -0.298 - (0.067)(1.751) = -0.415

S_3 = -0.298 - (-0.401)(2.036) = 0.518

A linear transformation can be used to place the scale values anywhere on the real number line with the equation $Y = \alpha + \beta x,\ \beta > 0$. Since upper bounds of 80.0 and 20.0 for the high and very low categories are desired, the linear transformation is performed. The values for and are calculated to be 75.405 and 17.605 by solving simultaneous equations. The transformed results are:

$$S_1 = (75.405) + (17.605)(-0.00852) = 75.3$$

$$S_2 = (75.405) + (17.605)(-0.415) = 68.1$$

$$S_3 = (75.405) + (17.605)(2.036) = 84.5$$

These are the transformed values for the 1000-pound bomb, Phoenix missile, and the MK-46 torpedo, respectively, from the fleet survey.

2. Scaling of Survey Results

The ten-step procedure for scaling categorical data outlined in the previous section was applied independently to each survey group to obtain scaled values from the categorical judgements of ordnance contribution to mission accomplishment. The columns of the raw frequency data array with values of zero had to be grouped with adjacent columns so that the Zij array would not be incomplete. The Zij array was also broken down into smaller, but complete Zij array problems. [Ref. 3:p.18-28] The results of the ten-step scaling procedure for data from the fleet survey are provided in Table 9, and illustrated in Figure 1. The results of the ten-step scaling procedure for data from the NPS survey are shown in Table 10, and illustrated in Figure 2.

TABLE 9. SCALING RESULTS FOR THE FLEET SURVEY

Problem 1	Scaled Value	Transformed Value to Problem 3 Scale
MK-46 TORPEDO	+0.518	84.5
1000 LB BOMB	-0.009	75.3
PHOENIX MISSILE	-0.415	68.1
Upper bound, high category	0.261	80.0
Upper bound, medium category	-0.858	60.3

Problem 2	Scaled Value	Transformed Value to Problem 3 Scale
SIDEWINDER MISSILE	0.356	65.8
SPARROW III	0.275	64.3
ROCKEYE	0.164	62.3
SHRIKE	-0.207	55.7
500 LB BOMB	-0.252	54.9
HARPOON MISSILE	-0.320	53.7
Upper bound, high category	1.153	80.0
Upper bound, medium category	0.037	60.3
Upper bound, low category	-1.082	40.1

Problem 3	Scaled Value	Transformed Values
HARM	1.252	86.1
ASROC	0.316	62.4
TOMAHAWK	0.214	59.8
WALLEYE	0.054	55.8
2000 LB BOMB	-0.073	52.5
STANDARD MISSILE	-0.199	49.3
SEASPARROW MISSILE	-0.476	42.3
5 INCH PROJECTILE	-0.708	36.4
Upper bound, high category	1.011	80.0
Upper bound, medium category	0.233	60.3
Upper bound, low category	-0.565	40.1
Upper bound, very low category	-1.357	20.0

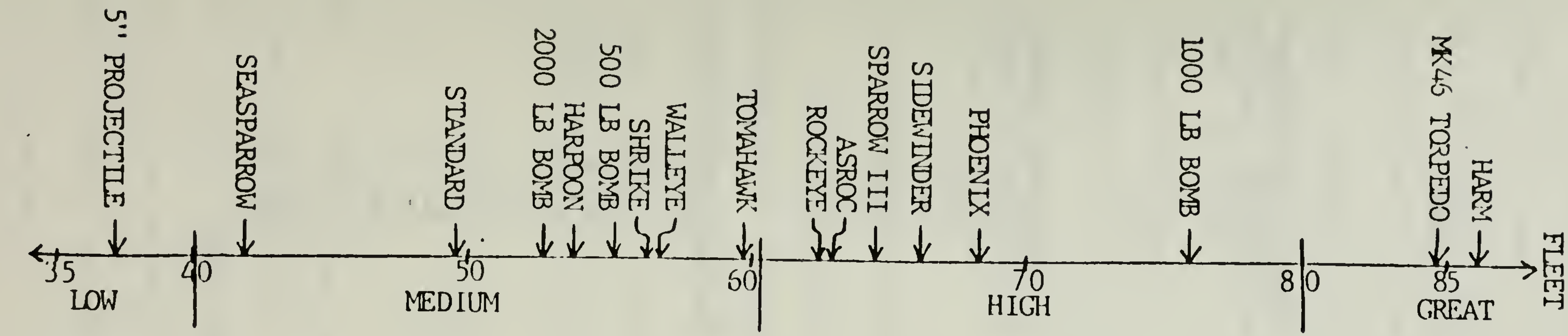

Figure 1. Transformed Results from the Fleet Survey, Indicating Relative Contribution to Success for the Given CBG Mission for 17 Ordnance Types.

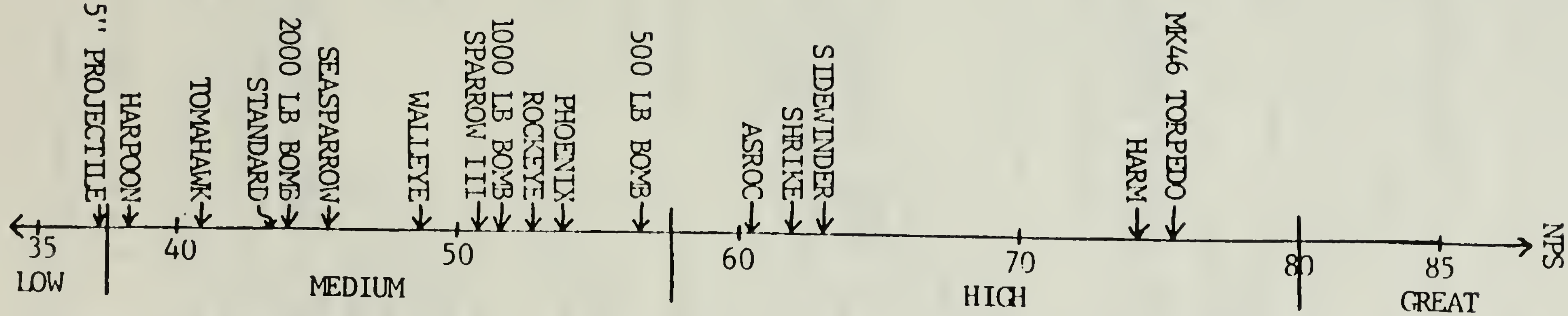

Figure 2. Transformed Results from the NPS Survey, Indicating Relative Contribution to Success for the Given CBG Mission for 17 Ordnance Types.

TABLE 10. SCALING RESULTS FOR THE NPS SURVEY

Problem 1	Scaled Value	Transformed Value to Problem 3 Scale
MK-46 TORPEDO	0.019	75.1
HARM	-0.035	74.2
Upper bound, high category	0.319	80.0
Upper bound, medium category	-0.979	57.1

Problem 2	Scaled Value	Transformed Value to Problem 3 Scale
SIDEWINDER MISSILE	0.507	62.8
1000 LB BOMB	-0.067	51.2
SPARROW III MISSILE	-0.087	50.8
STANDARD MISSILE	-0.442	43.5
Upper bound, high category	1.354	80.0
Upper bound, medium category	0.338	57.1
Upper bound, low category	-0.725	37.0

Problem 3	Scaled Value	Transformed Value
SHRIKE	0.564	61.6
ASROC	0.506	60.2
500 LB BOMB	0.353	56.3
PHOENIX MISSILE	0.218	53.4
ROCKEYE	0.155	51.9
WALLEYE	-0.006	48.1
SEASPARROW MISSILE	-0.477	45.1
2000 LB BOMB	-0.192	43.7
TOMAHAWK MISSILE	-0.304	41.0
HARPOON MISSILE	-0.438	37.8
5 INCH PROJECTILE	-0.477	36.9
Upper bound, high category	1.342	80.0
Upper bound, medium category	0.376	57.1
Upper bound, low category	-0.472	37.0
Upper bound, very low category	-1.191	20.0

A linear transformation was performed on the scaled values of each survey group to yield the transformed values in the right hand columns of the tables. The linear transformation was chosen so that the upper bound of the high category would be 80.0 and the upper bound of the very low category would be 20.0. This transformation ensured that all values would be between zero and 100, which is a convenient scale to show the relative importance of each ordnance type. It is also necessary to make the transformed values positive for use in the objective function of the linear program.

D. CORRELATION BETWEEN THE TRANSFORMED DATA SETS

The transformed data for each ordnance type in the two surveys are compared using the coefficient of correlation. The coefficient of correlation indicates the strength of the relationship between two variables. The correlation coefficient is calculated by using the equation:

$$r = \frac{\sum(X-\overline{X})(Y-\overline{Y})}{\sqrt{\sum(X-\overline{X})^2\sum(Y-\overline{Y})^2}} \quad (3.1)$$

The r value measures how well the least squares regression line fits the data. The value of r varies from -1 to +1. If r = +1, then there exists a perfect positive linear correlation between the two variables. If r = -1, then there exists a perfect negative linear correlation between the variables.

The NPS transformed data for ordnance contribution is assigned to the variable X and the fleet transformed data is assigned to the variable Y. The coefficient correlation, r, then is calculated to be 0.79 for the assigned values of X and Y. This is another measure of the consistency between the results of the two survey groups. A value of 0.79 for r indicates a strong positive correlation between the NPS and the fleet transformed data, as expected. A 95 percent confidence limit for r gives an upper bound of 0.92 and a lower bound of 0.50 for the correlation coefficient. The lower bound of 0.50 still shows a fairly strong positive linear correlation between the two variables. A scatter plot of NPS versus fleet transformed ordnance data is shown in Figure 3.

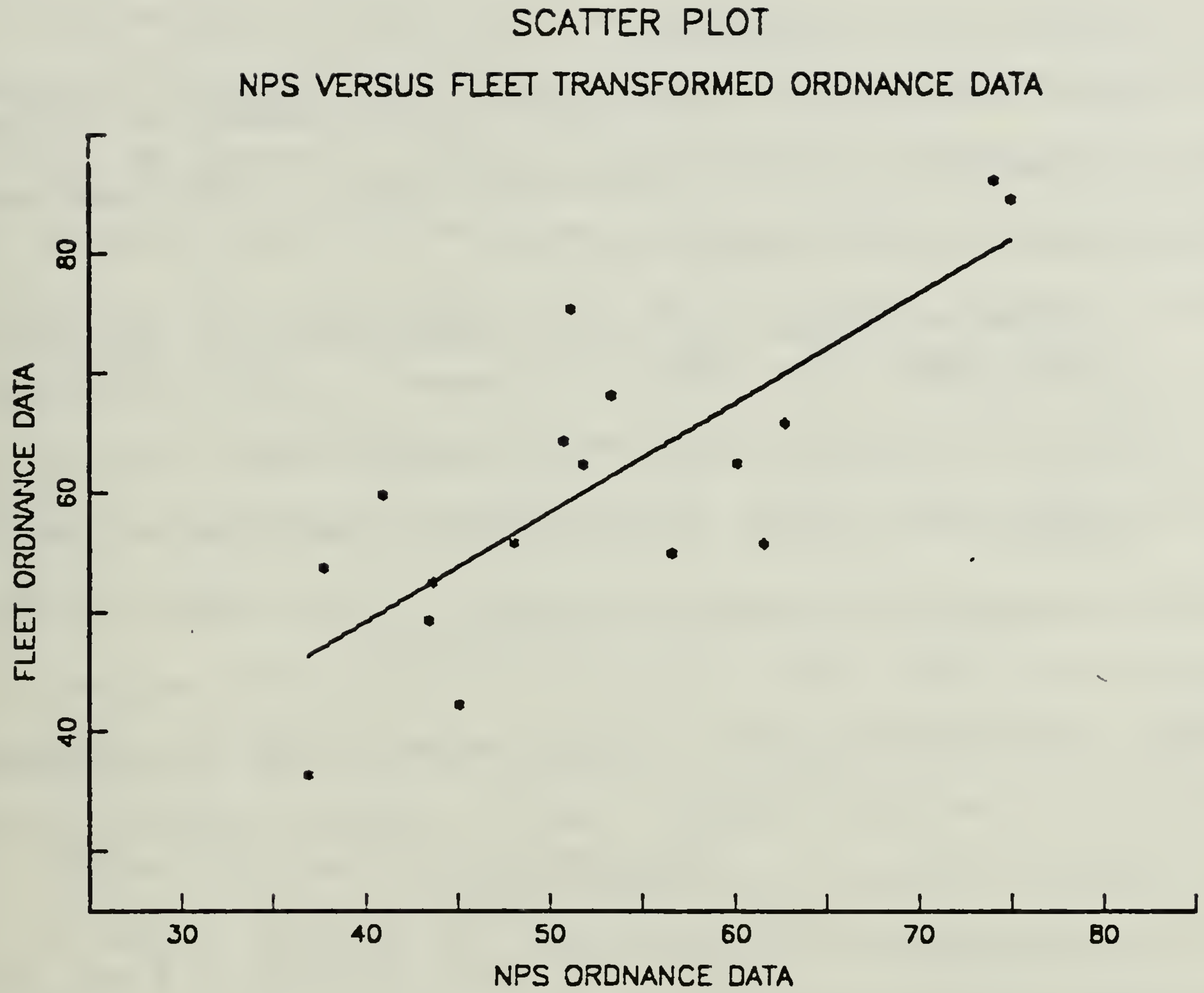

Figure 3. Scatter Plot of Transformed Ordnance Data

IV. LINEAR PROGRAM

A. CONSTRAINTS OF THE MODEL

There are several constraints on the amount of ordnance that can be loaded on an ammunition ship. The constraints considered in this model are

1. volume available in each compartment of the AE-26 class ammunition ship,
2. deck stress that each deck can withstand,
3. number and types of ammunition available to load, and
4. sea keeping qualities of the ship.

These constraints are incorporated into the General Algebraic Modeling System (GAMS) linear program model described in Section C of this Chapter.

The volume and weight of each ordnance type were obtained from the Naval Sea Systems Command NALC/DODIC Reference Report for loading ammunition aboard ships [Ref. 7]. The volume and deck stress of each compartment were obtained from various drawings of the AE-26 class ammunition ship. The deck stress constraint is an average deck load limit that represents the maximum allowable uniform load across the entire deck. Deck stress is calculated by dividing the total weight of the ordnance in the compartment (in pounds) by the square footage of usable deck space, to yield pounds per square foot.

The actual minimum and maximum quantity of each type of ordnance available to load on the AE-26 would not be known until a decision is made to load all the CLF ships for war. The minimum level of ordnance is the smallest amount of each ordnance type the decision maker wants loaded on the ammunition ship in support of the CBG. The maximum level represents the lesser of the available ordnance in stockpiles and the greatest amount of each ordnance type the decision maker wants loaded in support of the CBG. Minimum and maximum quantities of ordnance have been arbitrarily assigned for this study in order to demonstrate the model.

B. LINEAR PROGRAMMING ASSUMPTIONS

A major assumption of linear programming is that equations representing the objective function and the constraints are linear. The objective function assumption for this study is that the quantity of a given weapon, n, multiplied by a number representing the benefit of that particular weapon (obtained from the survey data), is n times more valuable for the CBG than just one weapon times the same benefit value. The constraints of the linear program used for this study consist of weights, volumes, and deck stresses that clearly are linearly related.

Another assumption necessary for the linear program is that the ordnance stowage load list output can be supported with sufficient manpower, handling equipment, stowage gear, and time to get the ordnance stowed securely aboard the ammunition ship. Ordnance stockpiles must be sufficient to meet the quantity of each ordnance type requested by the ammunition ship.

A third assumption of the linear program is that all ordnance loaded on the AE-26 can be transferred at sea and loaded aboard any ship in the CBG that requests the ordnance. The linear program does not specify where each particular ordnance item is to be placed on the individual decks. It is more important to find a preferred mix of ordnance that can fit aboard the AE-26 class ammunition ship, given the ordnance stowage constraints.

C. GAMS LINEAR PROGRAM

The linear program developed for this study was formulated using the GAMS algebraic modeling language. Equations can be written in GAMS using FORTRAN-like mathematical expressions with some efficiencies that FORTRAN does not have. GAMS statements can also be written in almost any style that is convenient for the user. The real power of GAMs is the use of concise algebraic statements that can be easily read by modelers, computers, and users. [Ref. 8]

The model used to maximize the total contribution of a weapon to CBG mission accomplishment is the GAMS linear program included as Appendix E. The key section of the linear program is the equations section, where the relationships between all of the input data are defined. A total of eight equations are used to specify the objective function and all constaints for the linear program.

The most important equation defines the linear objective function, called TOTAL for this study. The objective function consists of the following equation.

$$\sum_{D}\sum_{W}(B(W) \times X(W,D)) = Z \; . \qquad (4.1)$$

The objective function equation sums up the benefit of each ordnance type from the transformed fleet survey data, B(W), times the ordnance on each deck D of type W, X(W,D), over all ordnance types and all decks. The total benefit of the ordnance load after maximization is represented by the variable Z in equation 4.1.

The constraints of the GAMS program are modeled in the equations section of the linear program, as shown in Equations 4.2 to 4.8.

$$\sum_{W}(VOL(W) \times X(W,D)) + \sum_{AC}\sum_{W}(AVOL(AC) \times Y(W,AC,D)) \leq CF(D) \; . \qquad (4.2)$$

$$\sum_{W}(WT(W) \times X(W,D)) + \sum_{AC}\sum_{W}(AWT(AC) \times Y(W,AC,D)) \leq AD(D) . \quad (4.3)$$

$$\sum_{D}X(W,D) \geq WMIN(W) . \quad (4.4)$$

$$\sum_{D}X(W,D) \leq WMAX(W) . \quad (4.5)$$

$$\sum_{D}Y(W,AC,D) \geq REQ(W,AC) \times \sum_{D}X(W,D) . \quad (4.6)$$

$$\sum_{W}(WT(W) \times X(W,D)) \leq \sum_{W}(WT(W) \times X(W,\mathrm{DECK1})) . \quad (4.7)$$

$$\sum_{W}(WT(W) \times X(W,D)) \leq \sum_{W}(WT(W) \times X(W,\mathrm{DECK2})) . \quad (4.8)$$

Equation 4.2 ensures that the sum of the ordnance and accessories volume, VOL(W) and AVOL(AC), is less than or equal to the total usable volume of deck space available for each deck, CF(D). The deck stress constraint, Equation 4.3, is developed from the formula WT/AREA = DS, where WT is the weight of the ordnance in pounds, AREA is the area of usable deck space in square feet, and DS is the deck stress for a particular deck in pounds per square foot. Equation 4.3 ensures that the sum of the weight of all ordnance and accessories, WT(W) and AWT(AC), is less than or equal to the area times the maximum allowable deck stress in pounds for each deck, AD(D).

Equations 4.4 and 4.5 ensure that ordnance is not loaded below the minimum level, WMIN(W), or above the maximum level, WMAX(W), for each ordnance type. Equation 4.6 loads an ordnance accessory for every ordnance type loaded that has an associated accessory item.

Equations 4.7 and 4.8 ensure that the forward decks, deck one and deck two, have heavier ordnance loads than the decks located aft of these decks on the same level. This ordnance arrangement allows the AE-26 to ride smoother at sea because the heavy loads forward push the bow down into the sea where the hull configuration is most efficient.

The results of the GAMS linear program are shown in Table 11.

The model loads the ordnance at the minimum level for six ordnance types, at the maximum level for ten ordnance types, and close to the minimum level for one ordnance type. This combination of ordnance maximizes the objective function and satisfies all the constraints. The HARM missile and MK-46 torpedo are among weapons at maximum load levels and the five-inch projectile is close to the minimum load level. This result was expected because the fleet survey placed the highest value on the HARM and MK-46 and the lowest value on the five-inch projectile.

TABLE 11. LEVELS OF ORDNANCE FOR THE GAMS LINEAR PROGRAM

-	LOWER	LOAD LEVEL	UPPER
HARPOON	50	50	250
TOMAHAWK	50	50	300
MK46	125	400	400
STANDARD	40	150	150
SEASPARROW	30	100	100
SIDEWINDER	70	350	350
SPARROW III	70	70	250
PHOENIX	90	90	400
1000 LB BOMB	150	400	400
ROCKEYE	80	250	250
5" PROJECTILE	30	33	100
SHRIKE	50	50	150
2000 LB BOMB	70	120	120
WALLEYE	60	60	200
500 LB BOMB	90	200	200
ASROC	80	250	250
HARM	100	500	500

Appendix F includes a GAMS table that shows where the ordnance and accessories would be loaded on the ship. The quantities in the table can be rounded down to integer values that indicate the number of unit loads to be placed on each deck. Ordnance is loaded on the ship in unit loads, the number of rounds in the container or pallet that is used to hold the ordnance. The AE-26 ordnance storage volume would be filled to capacity in order to load the mix of ordnance listed in the table. The loading of most decks would be below the deck stress constraint.

The disadvantage of using a linear objective function is that the model proposes that all of the ordnance be loaded at the minimum or maximum level except for one ordnance type. The ordnance type loaded between the minimum and maximum level, the five-inch projectile in this case, is used to maximize the objective function and satisfy all of the constraints. The ordnance types loaded at the minimum and maximum levels do not give the AE-26 flexibility in fulfilling the ordnance requirements of the CBG.

D. SENSITIVITY ANALYSIS

The sensitivity analysis used for this study involves modifications to the objective function to observe the changes in the resulting ordnance load. The first case consists of changing the linear objective function to the following form.

$$\sum_{W}\sum_{D}\sqrt{B(W) \times X(W,D)} = Z \ . \qquad (4.9)$$

For this modification, the objective function is made nonlinear by using the square root operator. The program then was run using the nonlinear programming version of GAMS.

The results (Table 12) show that this model proposes levels of ordnance that are at the minimum level for two ordnance types and at the maximum level for nine ordnance types, while six lie between the minimum and maximum levels.

TABLE 12. LEVELS OF ORDNANCE FOR THE GAMS NONLINEAR PROGRAM

-	LOWER	LOAD LEVEL	UPPER
HARPOON	50	50	250
TOMAHAWK	50	92	300
MK46	125	400	400
STANDARD	40	150	150
SEASPARROW	30	100	100
SIDEWINDER	70	210	350
SPARROW III	70	76	250
PHOENIX	90	147	400
1000 LB BOMB	150	400	400
ROCKEYE	80	250	250
5" PROJECTILE	30	100	100
SHRIKE	50	80	150
2000 LB BOMB	70	120	120
WALLEYE	60	60	200
500 LB BOMB	90	200	200
ASROC	80	250	250
HARM	100	394	500

HARM and the MK-46 torpedo are loaded at high levels. The HARPOON cruise missile and the WALLEYE bomb are loaded at minimum levels. The ordnance levels resulting from this GAMS nonlinear program do not correspond exactly to the ordnance levels from the survey because some high value ordnance types are very heavy and take up considerable volume, which decreases the number that can be loaded. Appendix G shows the ordnance load for each deck on the AE-26 for the nonlinear objective function.

This nonlinear model differs from the linear programming model in that, in using it, a decision maker must feel that decreasing marginal returns are present in loading ordnance. In other words, the increase in total benefit from loading a given additional weapon, when that weapon level is high, will be less than the increase in total benefit from loading the same weapon when the loaded level is low. This nonlinear objective function may be a more reasonable model than the linear objective function because the decision maker may value an additional ordnance type differently near the minimum and maximum levels.

For the second sensitivity analysis, the objective function is changed so that the square of the difference between the ideal amount of ordnance, IDEAL(W), and the actual amount of ordnance loaded, X(W,D), is a minimum for each ordnance type.

$$\sum_{W}\sum_{D}(X(W,D) - IDEAL(W))^2 = Z \; . \qquad (4.10)$$

The ideal amount of ordnance is the amount of ordnance that the decision maker would like to load on the ship. For demonstration purposes, the ideal amount was calculated by averaging the minimum and maximum levels for each ordnance type as used in the program. The objective function, Equation 4.10, then was minimized using the nonlinear version of the GAMS program.

This change results in a model in which all the ordnance types are loaded between the minimum and maximum levels of ordnance, as provided in Table 13. The objective function penalizes any ordnance type loaded above or below the ideal level, so all ordnance types loaded are close to the ideal level. The advantage of this kind of ordnance loading method is that the decision maker has great flexibility in providing the CBG with ordnance support. The disadvantage is that high and low priority items are not loaded at high and low levels, respectively, reflecting their relative priorities. Appendix H shows the ordnance load for each deck on the AE-26 when using this final objective function.

TABLE 13. LEVELS OF ORDNANCE FOR THE IDEAL OBJECTIVE FUNCTION

-	LOWER	LOAD LEVEL	UPPER
HARPOON	50	131	250
TOMAHAWK	50	161	300
MK46	125	257	400
STANDARD	40	90	150
SEASPARROW	30	62	100
SIDEWINDER	70	200	350
SPARROW III	70	144	250
PHOENIX	90	233	400
1000 LB BOMB	150	269	400
ROCKEYE	80	157	250
5" PROJECTILE	30	59	100
SHRIKE	50	86	150
2000 LB BOMB	70	88	120
WALLEYE	60	116	200
500 LB BOMB	90	139	200
ASROC	80	157	250
HARM	100	292	500

V. SUMMARY OF RESULTS AND CONCLUSIONS

A. SUMMARY OF RESULTS

The goal of this study was to provide alternative optimal load lists of ordnance for the AE-26 class ammunition ship in a station ship role, based on a specific wartime scenario. The goal was accomplished by developing a wartime scenario in the form of a survey to obtain categorical judgements in order to prioritize various ordnance types. The results of the survey were scaled using Lindsay's ten-step procedure. The scaled values were then transformed to use as input into the objective function of a GAMS program written for the study.

The GAMS linear program was developed to optimize the mix of ordnance to be loaded on the AE-26 class ammunition ship given the constraints of the ship to hold ordnance. The primary constraints modeled were volume and deck stress limitations on the AE-26. Sensitivity analysis was conducted to observe the differences in ordnance loads caused by changes in the objective function. The output of the GAMS program is an ordnance load plan that considers the prioritization of ordnance from the survey, and also meets the constraints modeled. The levels of ordnance loaded for the three objective functions are shown in Tables 11, 12, and 13. The results of the GAMS output for the three objective functions are provided in Appendices F, G, and H; these show the quantity of ordnance to load on each deck of the AE-26.

B. CONCLUSIONS

The conclusions of this study are:

1. A survey can be used to elicit categorical responses from experts in order to prioritize ordnance for a given scenario.

2. There is no statistical difference between the survey responses from NPS and the fleet for ordnance preferences in this study, at an alpha level of 0.05.

3. The survey results can be scaled using Lindsay's ten-step method and linearly transformed for use in an optimization model such as GAMS.

4. There are advantages and disadvantages in using various types of objective functions in the GAMS program,as reflected in the optimal load lists. The decision maker has the ultimate responsibility of prioritizing the ordnance to be loaded aboard the ammunition ship. The objective function which ultimately is used in this model must reflect the decision maker's personnel objective function concerning ordnance loads for specific missions of the CBG.

5. For the scenario and ordnance presented to NPS and and fleet officers, the optimum loadouts for the AE-26 class ammunition ship are as shown in Appendices F, G, and H.

C. RECOMMENDATIONS FOR FUTURE STUDY

1. The GAMS program used in this study can be expanded to include all ordnance types and accessories that might be loaded on the AE-26 in wartime.

2. The GAMS program can be modified to accept selected ordnance requests from the CBG as input, once the war has started and some ordnance expenditure rates are known.

3. The GAMS program can be modified to indicate exactly where on each deck all ordnance should be placed to meet ship stability and ordnance compatibility constraints. A large GAMS program could reduce the effort required to calculate the ordnance load lists that are currently generated by hand.

4. The objective function of the GAMS program can be explored further to determine the advantages and disadvantages of objective functions not modeled in this study.

APPENDIX A: SURVEY INSTRUCTIONS

1. The following survey is designed to provide a method to determine a prioritization of ordnance to be loaded on an AE-26 class ammunition ship for the scenario outlined in enclosure (2). The data you provide will serve as input to a linear program that will calculate a preferred ordnance load for the AE-26 given the various constaints for loading ordnance on the ship.

2. You are requested to draw on your judgement and experience as a Naval officer in filling out the survey. There are no right or wrong answers, but it is your opinion that counts.

3. Please do not change any of your answers once you have thought about a response and have made a decision.

4. Each ordnance type is to be evaluated independently of the other ordnance listed in the survey.

5. Enclosure (3) will allow you an opportunity to make any specific comments you have about the survey.

6. If you have any questions or desire further information, please contact LT Kevin Rowland at the Operational Logistics Department of the Naval Postgraduate School (autovon 878-2786).

Enclosure (1)

APPENDIX B. SURVEY

ORDNANCE CONTRIBUTION TO MISSION ACCOMPLISHMENT

The scenario you are being asked to consider is a global conventional war with a Carrier Battle Group (CBG) consisting of the following ships: 1 CVN with a full airwing, 1 CG-26 Belknap class, 1 CG-47 Ticonderoga class with LAMPS III, 1 CGN-38 Virginia class, 1 DD-963 Spruance class with LAMPS III, and 1 DDG-993 Kidd class with LAMPS I. Preliminary intelligence reports indicate a high ASW threat, a medium AAW threat, and a low ASUW threat. The mission of the CBG consists of a primary mission to conduct strike operations on enemy bases preceding an amphibious invasion force landing, and a secondary mission to neutralize enemy submarines, defend the CBG against air attack, and prosecute enemy surface contacts within weapons release range.

Determine the contribution to the CBG mission accomplishment for one additional unit load corresponding to each ordnance type listed below. Assume the ordnance will be loaded on an AE-26 class ammunition ship that will carry a set minimum of each ordnance type. You are deciding which ordnance is more important to fill excess capacity of the AE-26 for one resupply to the CBG.

Place a mark in the block under the appropriate category for each ordnance type listed on the following page after

Enclosure (2)

reading through the ordnance and unit load lists. Remember to evaluate each ordnance type independently of the others. Please do not change the mark once you have made a decision and have placed the mark in the appropriate category.

	(CONTRIBUTION TO CVBG MISSION ACCOMPLISHMENT)				
ORDNANCE TYPE	VERY LOW	LOW	MEDIUM	HIGH	GREAT
SIDEWINDER					
1,000 LB BOMB					
HARPOON CRUISE MISSILE					
MK-46 TORPEDO					
PHOENIX MISSILE					
ROCKEYE					
5 INCH PROJECTILE					
TOMAHAWK CRUISE MISSILE					
SHRIKE					
SEASPARROW					
2,000 LB BOMB					
STANDARD					
WALLEYE					
500 LB BOMB					
HARM					
SPARROW III MISSILE					
ASROC					

Enclosure (2)

UNIT LOADS

	ROUNDS/UNIT LOAD
SIDEWINDER	8
1000 LB BOMB	3
HARPOON	1
MK-46	2
PHOENIX	2
ROCKEYE	2
5 INCH PROJECTILE	39
TOMAHAWK	1
SHRIKE	6
SEASPARROW	1
2000 LB BOMB	2
STANDARD	1
WALLEYE	1
500 LB BOMB	6
HARM	1
SPARROW	3
ASROC	1

Enclosure (2)

APPENDIX C. RATER QUESTIONNAIRE

Please complete the following:

1. Present rank __________ Designator __________

2. Amount of time spent on active duty: _____ years

   _____ months

3. Amount of time as a staff officer: _____ years

   _____ months

4. Was the scenario presented in the survey understandable? If not, please comment.

5. Are the ordnance types listed in the survey representative of the priority items a CVBG might have in order to carry out its mission? Would you add any other ordnance to the list?

6. Other comments about the survey, including any comments about how you responded to the survey:

Enclosure (3)

APPENDIX D. CHI-SQUARE TEST RESULTS

ORDNANCE	TRANSFORMED SURVEY VALUES FLEET	NPS	Q	k	ACCEPT/REJECT Ho
SIDEWINDER	65.8	62.8	3.8	7.815	ACCEPT
1000 LB BOMB	75.3	51.2	13.1	5.991	**REJECT**
HARPOON	53.7	37.8	4.8	7.815	ACCEPT
MK-46	84.5	75.1	5.4	5.991	ACCEPT
PHOENIX	68.1	53.4	3.7	5.991	ACCEPT
ROCKEYE	62.3	51.9	5.6	7.815	ACCEPT
5" PROJECTILE	36.4	36.9	0.7	9.488	ACCEPT
TOMAHAWK	59.8	41.0	6.3	9.488	ACCEPT
SHRIKE	55.7	61.6	2.7	7.815	ACCEPT
SEASPARROW	42.3	45.1	1.2	9.488	ACCEPT
2000 LB BOMB	52.5	43.7	2.1	9.488	ACCEPT
STANDARD	49.3	43.5	1.4	7.815	ACCEPT
WALLEYE	55.8	48.1	2.9	9.488	ACCEPT
500 LB BOMB	54.9	56.6	0.9	7.815	ACCEPT
HARM	86.1	74.2	0.7	5.991	ACCEPT
SPARROW III	64.3	50.8	5.6	7.815	ACCEPT
ASROC	62.4	60.2	3.8	9.488	ACCEPT

NOTE:

1. The null hypothesis (Ho) is rejected if $Q > k$.
2. Q is the chi-square statistic from Equation 2.1.
3. k is the critical value of the chi-square distribution from a table look up.

APPENDIX E. GAMS LINEAR PROGRAM

This GAMS linear program was developed to load an AE-26 class ammunition ship with ordnance. The objective function accommodates any positive-number weighting scheme that a decision maker may choose for prioritizing ordnance. The objective function can be changed to reflect the desires of the decision maker concerning the flexibility of ordnance loadouts.

An ordnance accessory must be loaded with the associated ordnance type. Ship stability and ordnance compatability are not modeled in this program. However, the program does load the heaviest ordnance forward in the AE-26 to allow the ship to ride smoothly at sea. The output of the GAMS program indicates how much ordnance and associated accessories should be stored on each deck to maximize the objective function and meet all the constraints modeled. The major constraints are volume and deck stress limitations on the AE-26.

Ordnance abbreviations used in this program are:
HAR - HARPOON cruise missile, TOM - TOMAHAWK cruise missile, M46 - MK-46 torpedo, STD - STANDARD missile, SEA - SEASPARROW missile, SID - SIDEWINDER missile, SPA - SPARROW III missile, PHE - PHOENIX missile, 1LB - 1000 pound bomb, ROC - ROCKEYE cluster bomb, PRO - five inch projectile, SHR - SHRIKE missile, 2LB - 2000 pound bomb, WAL - WALLEYE glide bomb, 5LB - 500 pound bomb, ASR - ASROC missile, HRM - HARM missile.

The following ordnance accessory abbreviations are added to the ordnance abbreviations in the program:
IA - ignitor assembly, WA - wing assembly, WF - wing and fin assembly, F - fins, C - charge, W - wings.

```
SETS
    W  types of ordnance /HAR, TOM, M46, STD, SEA, SID, SPA, PHE,
                     1LB, ROC, PRO, SHR, 2LB, WAL, 5LB, ASR, HRM/

    D  number of decks  /DECK1*DECK14/

    AC ordnance accessories /M46IA, SIDWA, SPAWF, PHEWA, 1LBF, PROC,
                        SHRW, SHRF, 2LBF, WALW, WALF, 5LBF, ASRIA/ ;

PARAMETER VOL(W)  volume in cubic feet of each ordnance type
    /HAR  269
     TOM  193
     M46   77
     STD   64
     SEA   40
     SID   98
     SPA  163
     PHE  105
     1LB   36
     ROC  111
     PRO   38
     SHR  127
     2LB   56
     WAL  108
     5LB   36
     ASR  106
     HRM  112/  ;

PARAMETER AVOL(AC)  volume in cubic feet of each ordnance accessory
    /M46IA     1
     SIDWA    36
     SPAWF    56
     PHEWA    58
     1LBF     42
     PROC     44
     SHRW     36
     SHRF     36
     2LBF     43
     WALW     81
     WALF     81
```

```
     3LBF    48
     ASRIA     1/  ;

PARAMETER WT(W)  weight in lbs of each ordnance type divided by 1000
    /HAR  3.585
     TOM  4.273
     M46  1.596
     STD  1.450
     SEA   .868
     SID  2.233
     SPA  3.949
     PHE  2.550
     1LB  1.632
     ROC  2.910
     PRO  3.779
     SHR  3.420
     2LB  4.113
     WAL  2.907
     3LB  3.228
     ASR  1.632
     HRM  2.068/  ;

PARAMETER AWT(AC)   weight in lbs of each ord accessory divided by 1000
    /M46IA     .083
     SIDWA     .531
     SPAWF   1.718
     PHEWA     .619
     1LBF      .740
     PROC    1.676
     SHRW    1.440
     SHRF    1.330
     2LBF      .685
     WALW    1.060
     WALF    1.060
     3LBF      .792
     ASRIA     .083/  ;

PARAMETER B(W)  benefit in the objective function of ea. ordnance type
    /HAR  53.7
     TOM  59.8
     M46  84.5
     STD  49.3
     SEA  42.3
     SID  65.8
     SPA  64.3
     PHE  68.1
     1LB  75.3
     ROC  62.3
     PRO  36.4
     SHR  55.7
     2LB  52.5
     WAL  55.8
     3LB  54.9
     ASR  62.4
     HRM  86.1/  ;

PARAMETER CF(D)  cubic feet of deck space
          /DECK1     9882
           DECK2     9592
           DECK3    28378
           DECK4    25000
           DECK5    20944
           DECK6    10073
           DECK7    31190
           DECK8    33422
           DECK9    34487
           DECK10   18851
           DECK11   28310
           DECK12   28310
           DECK13   42451
           DECK14   23212/ ;
```

```
PARAMETER AD(D)  area of deck times deck stress divided by 1000 in lbs
         /DECK1   561.5
          DECK2   708.5
          DECK3   1218.7
          DECK4   1420.5
          DECK5   1547
          DECK6   1295.1
          DECK7   1339.45
          DECK8   1899
          DECK9   2547.35
          DECK10  2423.7
          DECK11  1125.95
          DECK12  1608.5
          DECK13  3138.2
          DECK14  2984.4/ ;

PARAMETER WMIN(W)     minimum number of each ordnance type
         /HAR   50
          TOM   50
          M46  125
          STD   40
          SEA   30
          SID   70
          SPA   70
          PHE   90
          1LB  150
          ROC   80
          PRO   30
          SHR   50
          2LB   70
          WAL   60
          5LB   90
          ASR   80
          HRM  100/  ;

PARAMETER WMAX(W)     maximum number of each ordnance type
         /HAR  250
          TOM  300
          M46  400
          STD  150
          SEA  100
          SID  350
          SPA  250
          PHE  400
          1LB  400
          ROC  250
          PRO  100
          SHR  150
          2LB  120
          WAL  200
          5LB  200
          ASR  250
          HRM  500/  ;

PARAMETER REQ(W,AC)
         /M46.M46IA    1
          SID.SIDWA    1
          SPA.SPAWF    1
          PHE.PHEWA    1
          1LB.1LBF     1
          PRO.PROC     1
          SHR.SHRW     1
          SHR.SHRF     1
          2LB.2LBF     1
          WAL.WALW     1
          WAL.WALF     1
          5LB.5LBF     1
          ASR.ASRIA    1/  ;

PARAMETER
   BBB(D)
   AAA(D)  ;
```

```
   AAA(D) = 0;
   AAA('DECK4') = 1;
   AAA('DECK8') = 1;
   AAA('DECK12') = 1;

   BBB(D) = 0;
   BBB('DECK5') = 1;
   BBB('DECK9') = 1;
   BBB('DECK13') = 1;

VARIABLES
    X(W,D)      ordnance on each deck of type w
    Z           total benefit of ordnance load
    Y(W,AC,D)   ordnance accessories for each ordnance type and each
                accessory on every deck

POSITIVE VARIABLE X , Y ;

EQUATIONS
    VOLUME(D)         observes volume limit for each deck
    DS(D)             observes deck stress limit for each deck
    MINREQ(W)         satisfies the min requirement for each ordnance type
    MAXREQ(W)         observes the max limit for each ordnance type
    ACREQ(W,AC)       observes the requirement for ordnance accessories
    CGA(D)            defines center of gravity constraint for deck 1
    CGB(D)            defines center of gravity constraint for deck 2
    TOTAL             defines objective function ;

VOLUME(D) ..  SUM(W, VOL(W)*X(W,D)) +
       SUM(AC, SUM(W $ (REQ(W,AC) GT 0), AVOL(AC)*Y(W,AC,D)) ) =L= CF(D);

DS(D)     ..   SUM(W, WT(W)*X(W,D))
     + SUM(AC, SUM(W $ (REQ(W,AC) GT 0), AWT(AC)*Y(W,AC,D)) ) =L= AD(D);

MINREQ(W) .. SUM(D, X(W,D)) =G= WMIN(W) ;

MAXREQ(W) .. SUM(D, X(W,D)) =L= WMAX(W) ;

ACREQ(W,AC) $ (REQ(W,AC) GT 0)..
           SUM(D, Y(W,AC,D)) =G= REQ(W,AC) * SUM(D, X(W,D)) ;

CGA(D)$AAA(D)..
           SUM(W,WT(W) * X(W,D)) =L= SUM(W,WT(W) * X(W,'DECK1')) ;

CGB(D)$BBB(D)..
           SUM(W,WT(W) * X(W,D)) =L= SUM(W,WT(W) * X(W,'DECK2')) ;

TOTAL      .. SUM(D, SUM(W, B(W) * X(W,D)))  =E= Z ;

MODEL NEW /ALL/ ;

SOLVE NEW USING LP MAXIMIZING Z  ;

PARAMETERS VOLUSE(D), ACTDS(D);
VOLUSE(D) = SUM(W,VOL(W) * X.L(W,D)) +
    SUM(AC, SUM(W $ (REQ(W,AC) GT 0), AVOL(AC) * Y.L(W,AC,D)) )  ;

ACTDS(D) =  SUM(W, WT(W) * X.L(W,D)) +
    SUM(AC, SUM(W $ (REQ(W,AC) GT 0), AWT(AC)  * Y.L(W,AC,D)) )  ;
DISPLAY X.L, Y.L, VOLUSE, ACTDS ;
```

APPENDIX F. GAMS LINEAR PROGRAM OUTPUT

---- 235 VARIABLE X.L ORDNANCE ON EACH DECK OF TYPE W

	DECK1	DECK2	DECK3	DECK4	DECK5	DECK6	DECK7	DECK8	DECK9	DECK10
HAR								16.512		
M46							400.000			
STD			150.000							
SEA			100.000							
SID	15.155	22.842	150.796					161.207		
SPA				28.742						
PHE				90.000						
1LB	203.363									
ROC					159.252	90.748				
PRO	21.731			12.074						
2LB				14.398					98.269	
WAL								10.319	49.681	
5LB		193.152								
HRM					29.170		3.482		60.879	55.812

+	DECK11	DECK12	DECK13	DECK14
HAR	20.762		12.726	
TOM	50.000			
SPA	41.258			
1LB			196.637	
SHR	50.000			
2LB		7.333		
5LB		6.848		
ASR		60.672	189.328	
HRM		143.407		207.250

---- 235 VARIABLE Y.L ORDNANCE ACCESSORIES FOR EACH ORDNANCE TYPE AND EACH DECK

	DECK1	DECK2	DECK4	DECK8	DECK9	DECK10	DECK12	DECK13
M46.M461A		400.000						
SID.SIDWA						350.000		
SPA.SPAWF				70.000				
PHE.PHEWA								90.000
1LB.1LBF					400.000			
PRO.PROC				33.805				
SHR.SHRW				50.000				
SHR.SHRF								50.000
2LB.2LBF							120.000	
WAL.WALW				60.000				
WAL.WALF								60.000
5LB.5LBF			200.000					
ASR.ASR1A	250.000							

APPENDIX G. GAMS NONLINEAR OBJECTIVE FUNCTION OUTPUT

---- 244 VARIABLE X.L ORDNANCE ON EACH DECK OF TYPE W

	DECK1	DECK2	DECK3	DECK4	DECK5	DECK6	DECK7	DECK8	DECK9	DECK10
HAR	10.899	7.224		3.9140E-4	0.576			14.206		
TOM						16.125	2.021			45.546
M46							400.000			
STD			150.000							
SEA			100.000							
SID			150.796					59.653		
PHE				138.743						8.456
1LB	137.561									
ROC					187.289	62.711				
PRO	45.998			21.893				20.936		
2LB		0.870							112.998	
HAL								60.000		
5LB		200.000								
HRM									101.420	14.255

+	DECK11	DECK12	DECK13	DECK14
HAR			17.096	
TOM	28.506			
SPA	76.993			
1LB			262.439	
PRO		11.173		
SHR	80.776			
2LB		6.131		
ASR		35.860	114.140	
HRM		71.258		207.250

---- 244 VARIABLE Y.L ORDNANCE ACCESSORIES FOR EACH ORDNANCE TYPE AND EACH DECK

	DECK1	DECK2	DECK4	DECK8	DECK9	DECK10	DECK12	DECK13
M46.M461A		400.000						
SID.SIDWA						210.449		
SPA.SPAWF				76.993				
PHE.PHEWA								147.198
1LB.1LBF					400.000			
PRO.PROC				100.000				
SHR.SHRW				80.776				
SHR.SHRF								80.776
2LB.2LBF							120.000	
HAL.HALW				60.000				
HAL.HALF								60.000
5LB.5LBF			200.000					
ASR.ASR1A	250.000							

APPENDIX H. OUTPUT OF GAMS NONLINEAR OBJECTIVE FUNCTION WITH IDEAL ORDNANCE LEVELS

---- 240 VARIABLE X.L ORDNANCE ON EACH DECK OF TYPE W

	DECK1	DECK2	DECK3	DECK4	DECK5	DECK6	DECK7	DECK8	DECK9	DECK10
HAR								67.594	24.579	
TOM				24.072		9.398	75.071		3.789	4.465
M46			117.276							139.800
STD			90.550							
SEA	62.219									
SPA						50.669				
PHE									233.665	
ROC	6.703									
PRO	59.298									
SHR		14.823		5.604				65.735		
2LB	39.906	48.210								
HAL				116.857						
5LB		139.159								
ASR							157.560			
HRM					187.000					

+	DECK11	DECK12	DECK13	DECK14
HAR				39.122
TOM	44.783			
SID	200.682			
SPA			16.260	77.842
1LB		269.576		
ROC		7.486	143.093	
HRM			105.212	

---- 240 VARIABLE Y.L ORDNANCE ACCESSORIES FOR EACH ORDNANCE TYPE AND EACH DECK

	DECK1	DECK3	DECK4	DECK8	DECK9	DECK10	DECK12	DECK13
M46.M461A	257.076							
SID.SIDWA						200.682		
SPA.SPAWF			6.109				115.217	23.445
PHE.PHEWA		233.665						
1LB.1LBF							269.576	
PRO.PROC					59.298			
SHR.SHRW				86.162				
SHR.SHRF	48.515							37.647
2LB.2LBF				88.116				
HAL.HALF								116.857
5LB.5LBF			139.159					
ASR.ASRIA	157.560							

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